High Voltage Generation and Breakdown

WINP2015: Workshop on the Intermediate Neutrino Program

Sarah Lockwitz, FNAL

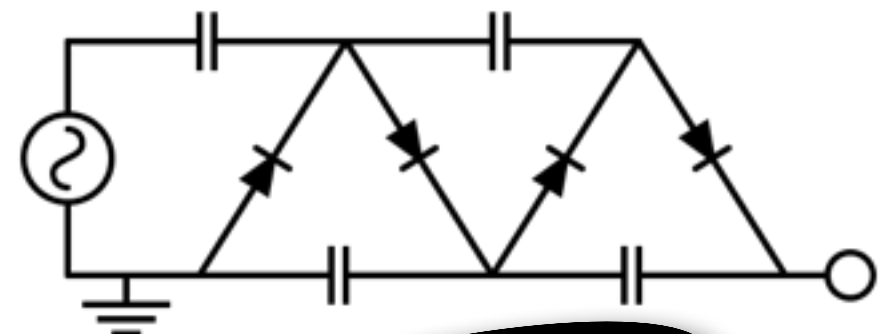
February 5, 2015

Brief Outline

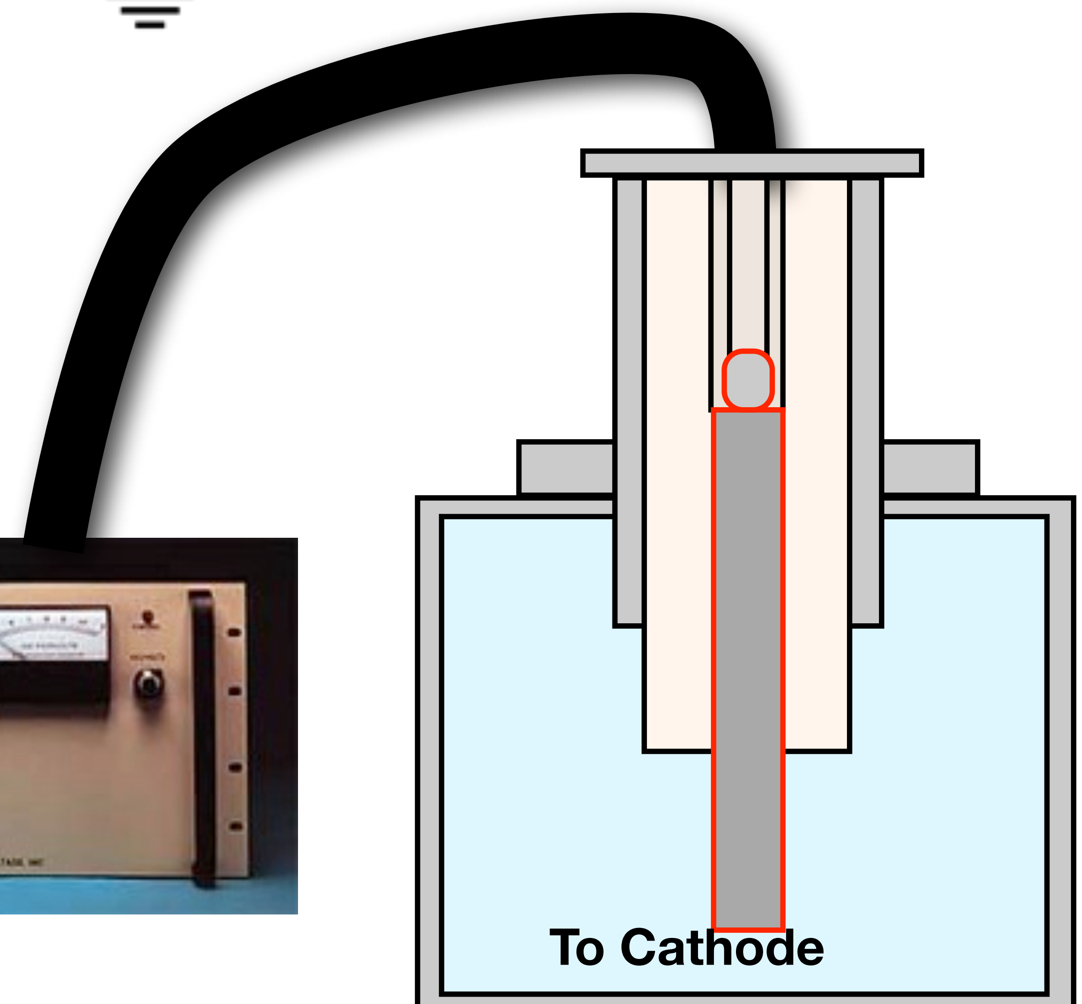
- HV generation
- Dielectric breakdown
- Potential impact on experiments
- Damage avoidance and mitigation

High Voltage Generation

- HV is needed to make the drift field to collect the signal electrons in TPCs
- HV has been supplied in two ways:
  - Greinacher/Cockcroft Walton
  - HV generated inside -- no feedthrough
    - Argontube at AEC-LHEP Bern
    - ETH Zurich group is also using this
  - Commercial HV power supply & custom HV feedthrough to TPC cathode
    - ICARUS, MicroBooNE, ArgoNeuT/LArIAT, 35T

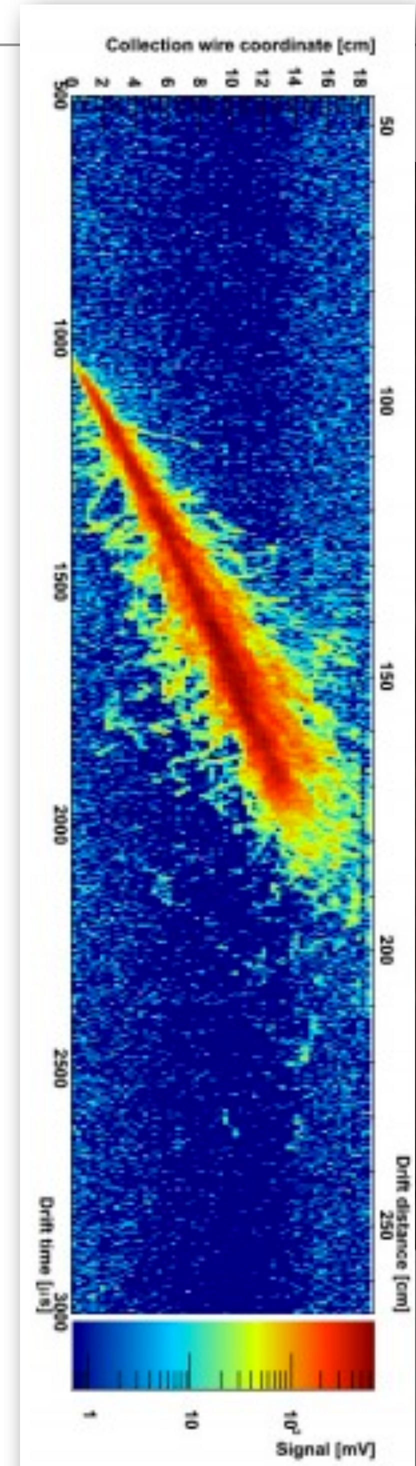


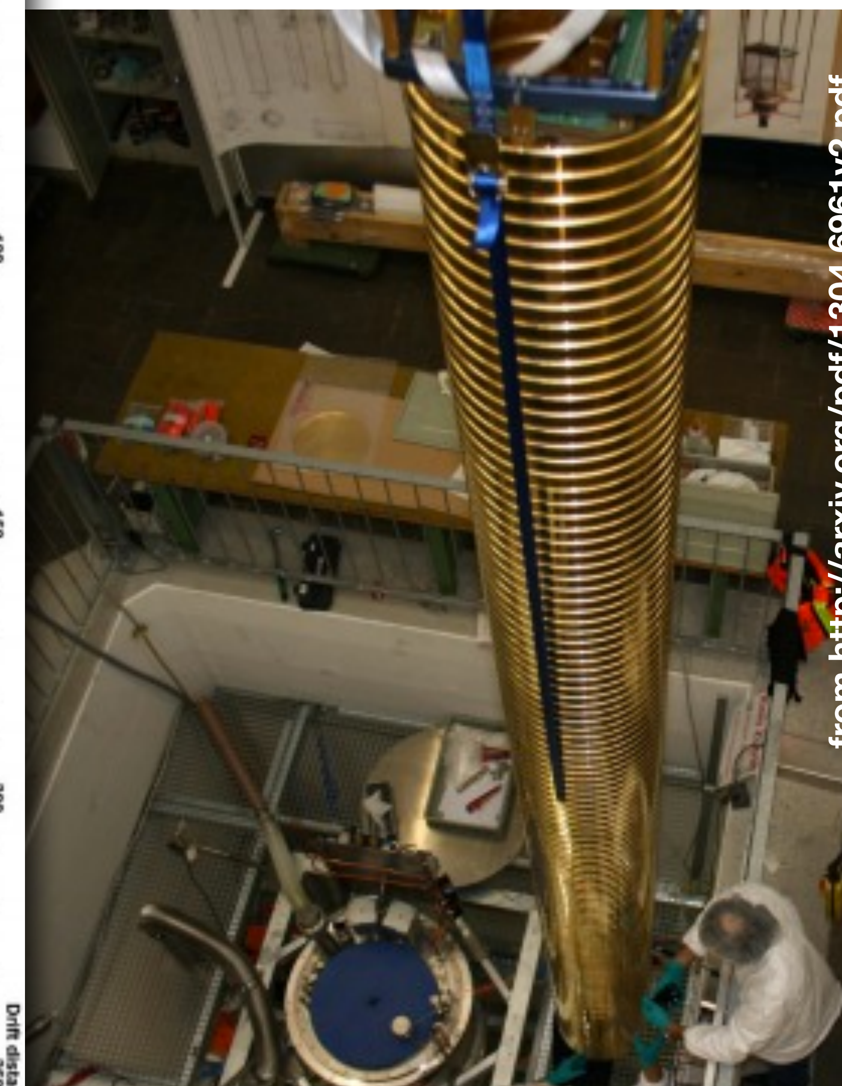
from Wikipedia



Greinacher/Cockcroft Walton Experience

- Argontube was able to successfully run at 125 kV and collect beautiful tracks over a 5 m drift. (http://arxiv.org/abs/1408.6635)
- There were some issues raising this voltage to the design of 500 kV
    - Breakdown was observed with $V_{cathode} > 150$ kV
    - Given the design, this corresponds to E_{max} ~56 kV/cm on the TPC
    - Coating will improve breakdown voltage, test in progress
    - Charging takes time for uniform field





HV Feedthroughs

- Can be a source of breakdown
  - Here, we're largely concerned with breakdown along the feedthrough (either instantaneous or delayed)
    - Surface conductivities and charge behavior are not well known*

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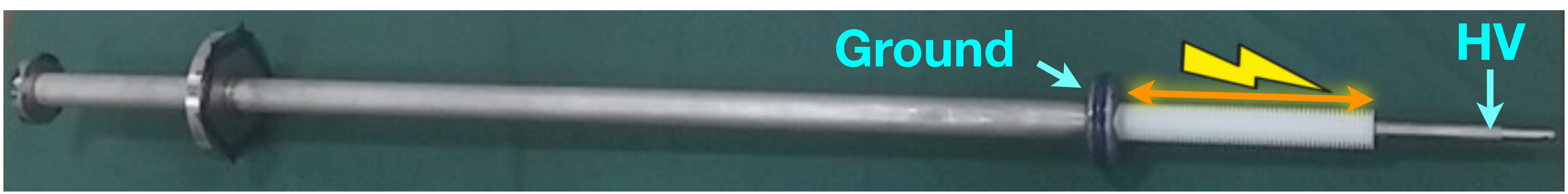

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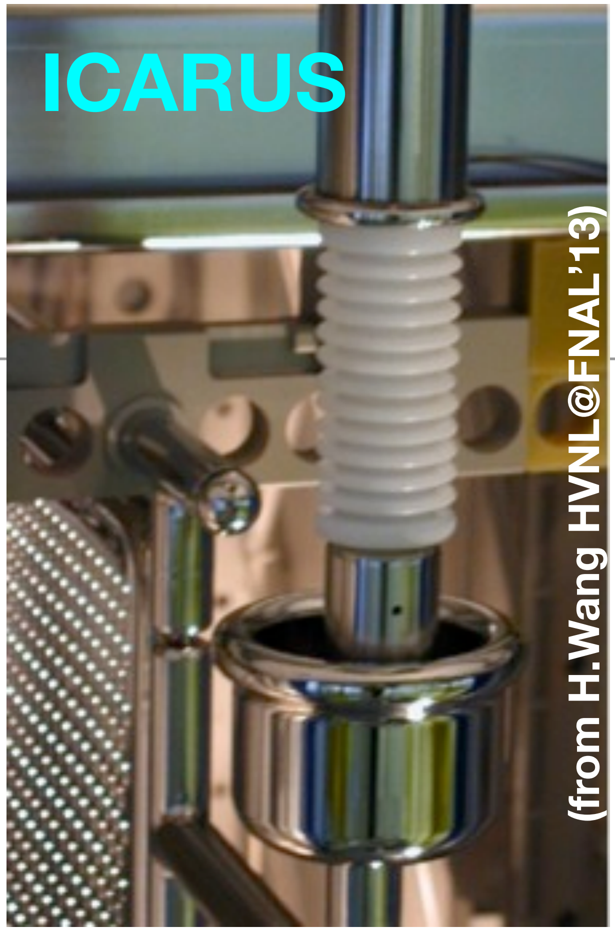

HV Feedthroughs

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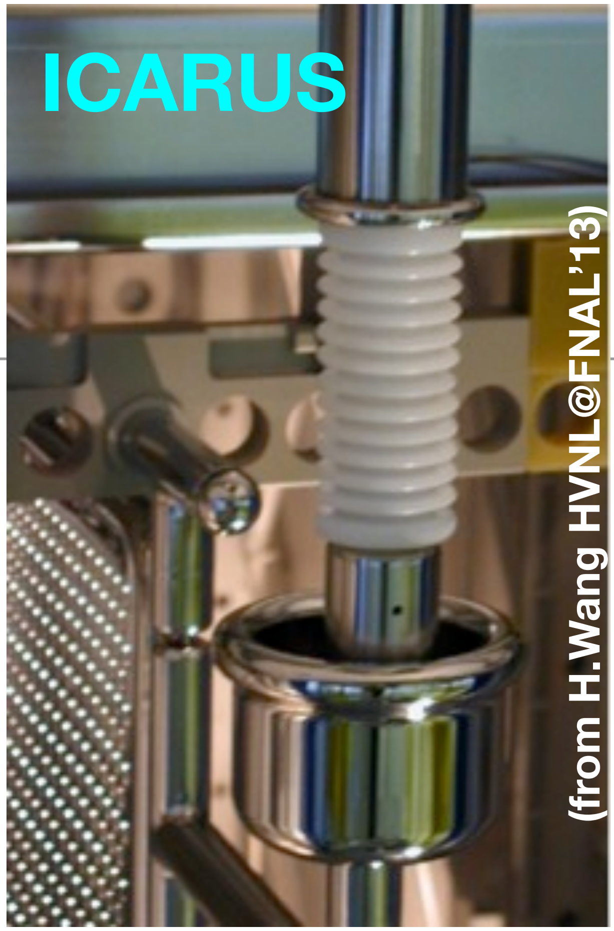

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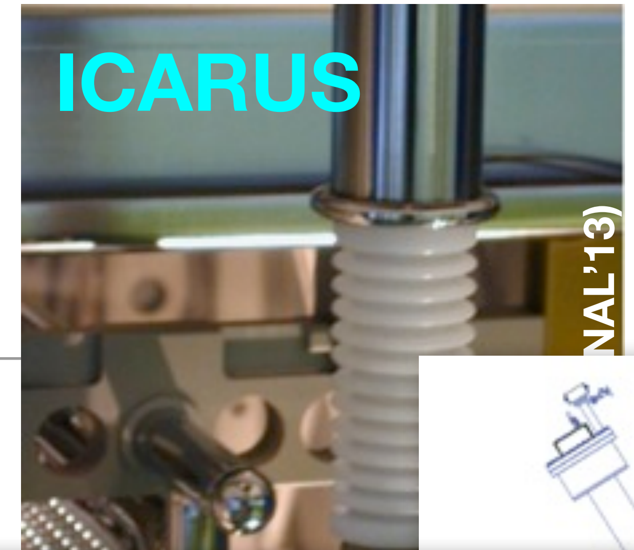
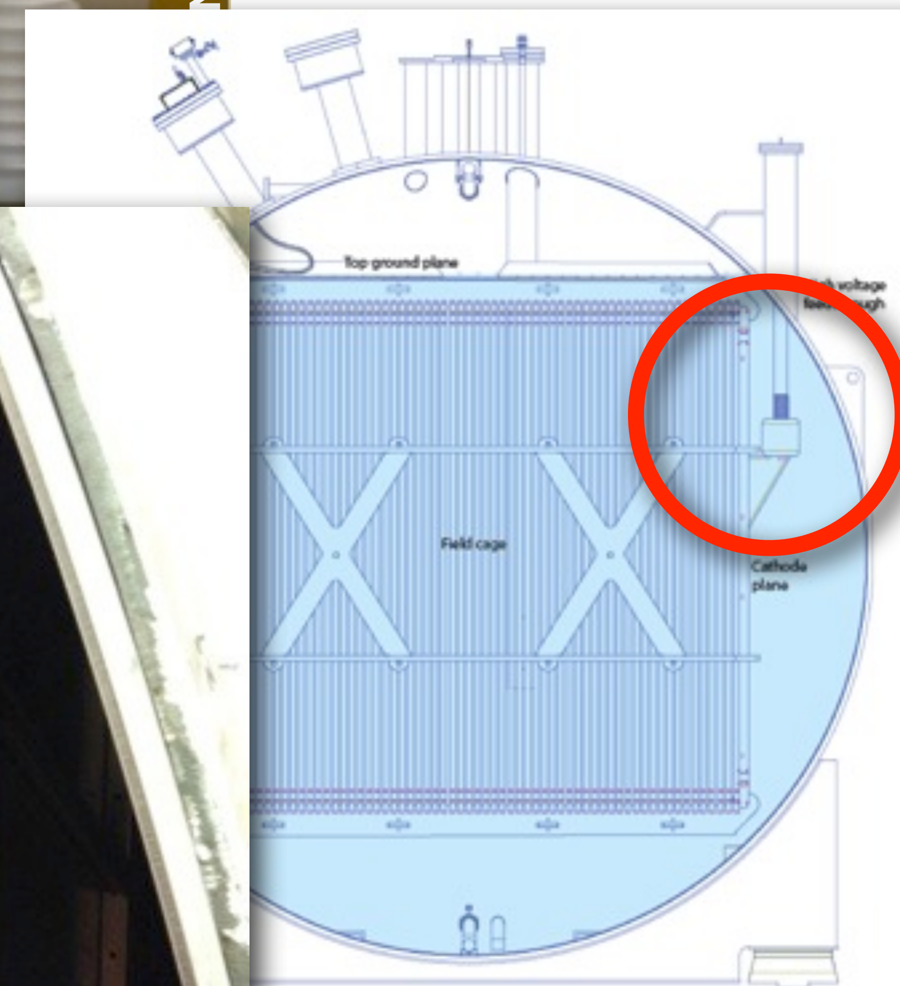
    - Tested successfully at 128 kV for 3 days in test cryostat until we ran out of LAr





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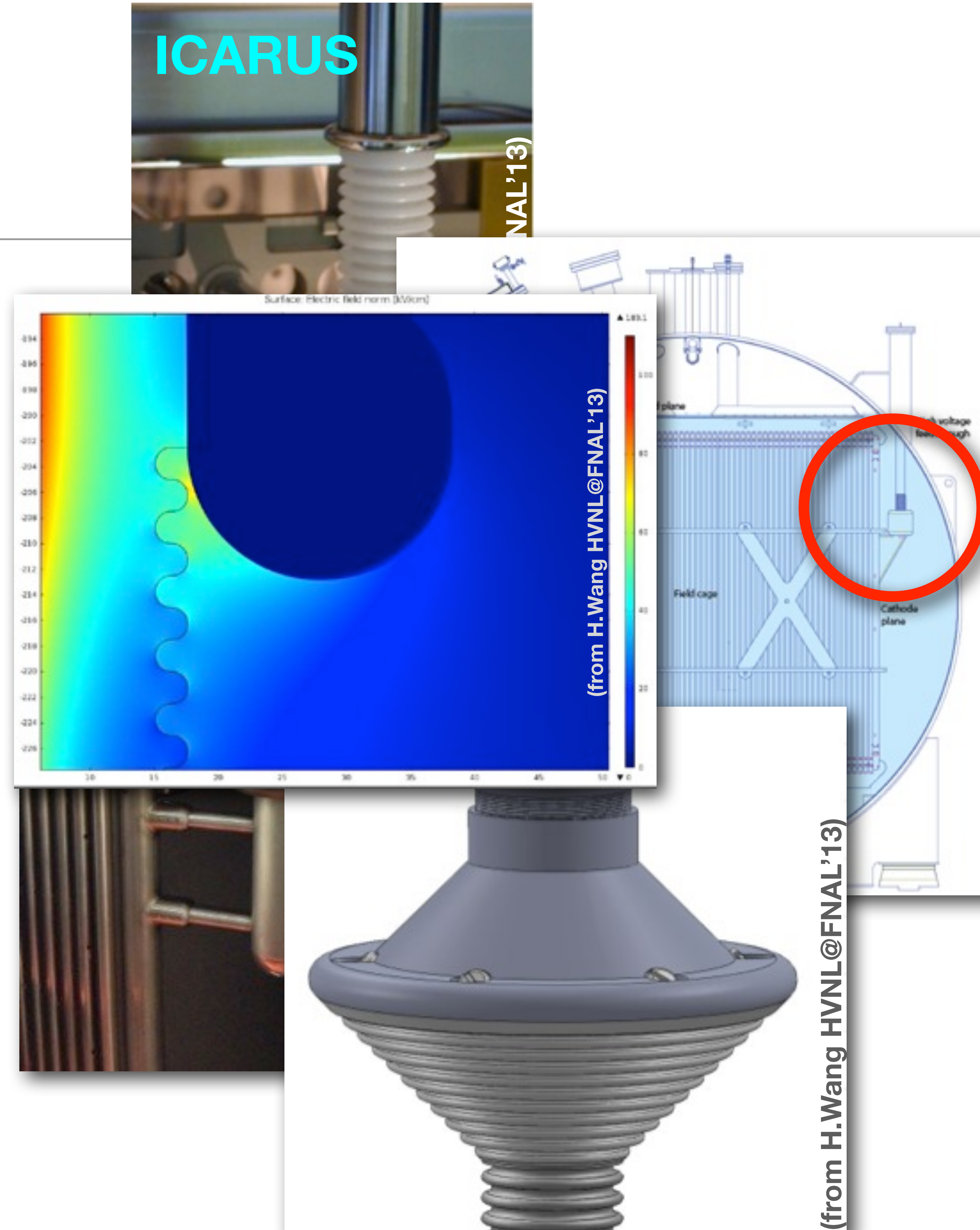
- MicroBooNE's geometry necessitated a longer design
    - Tested successfully at 128 kV for 3 days in test cryostat until we ran out of LAr
- 35 T/ELBNF has a feedthrough designed for even higher voltages
    - High field region is handled by a "plug" piece (H. Wang & A. Teymourian)



HV Breakdown

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- It is crucial to understand breakdown through LAr
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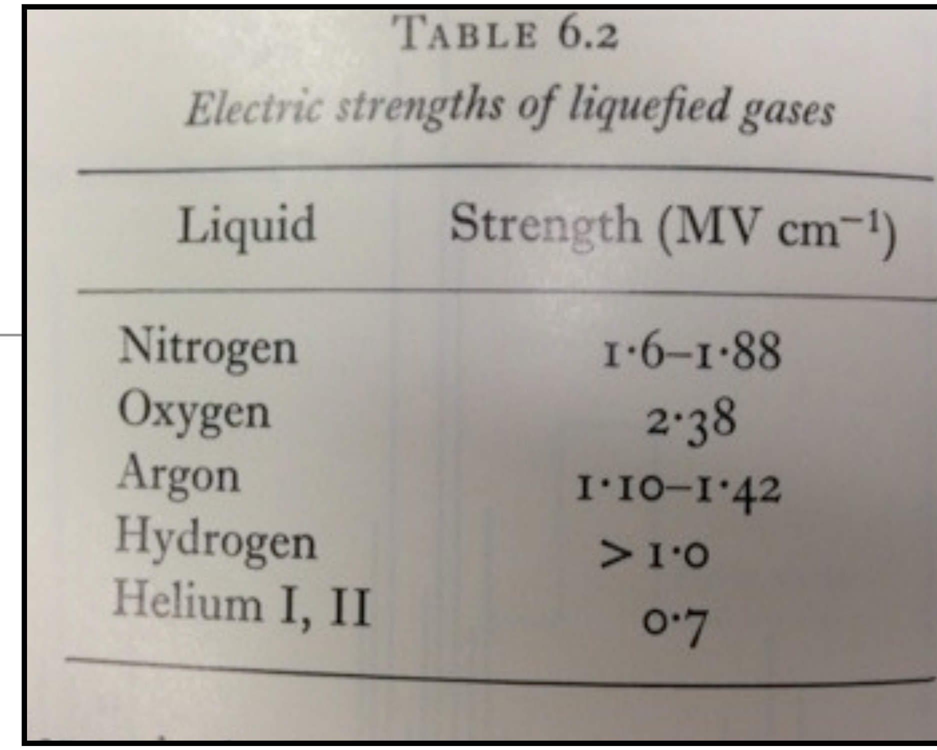

TABLE 6.2

Electric strengths of liquefied gases

Liquid	Strength (MV cm^{-1})
Nitrogen	1·6–1·88
Oxygen	2·38
Argon	1·10–1·42
Hydrogen	> 1·0
Helium I, II	0·7

from High-Voltage Technology, L.L. Alston ed. (1968)

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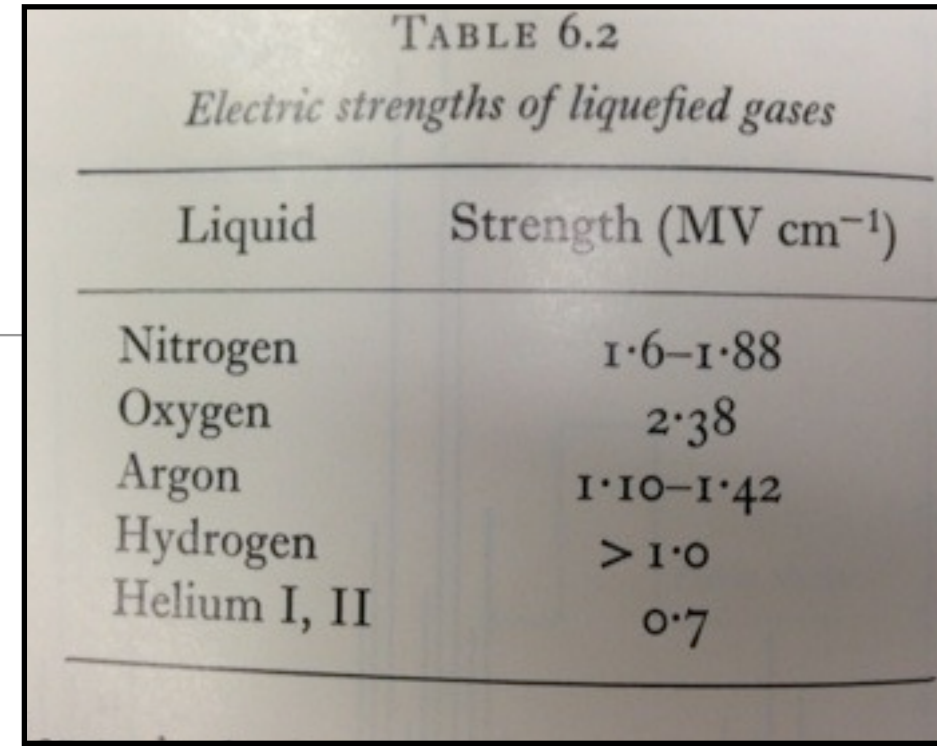

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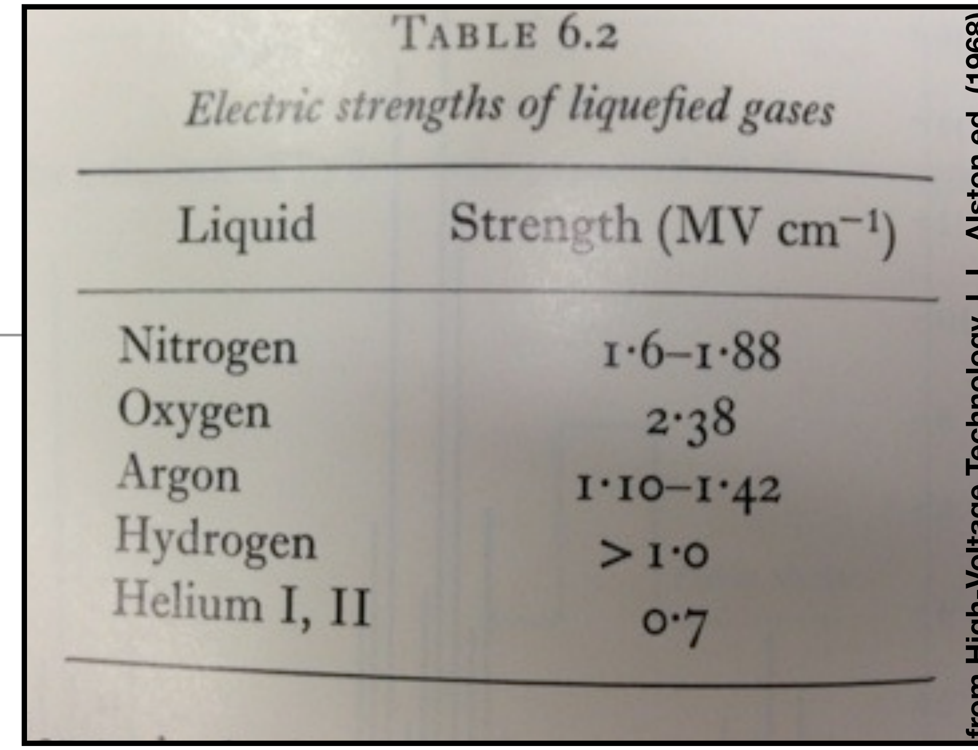
- This comes from a Swan 1960 study using 5 mm spheres at sub-mm distances
    - Should not be extrapolated



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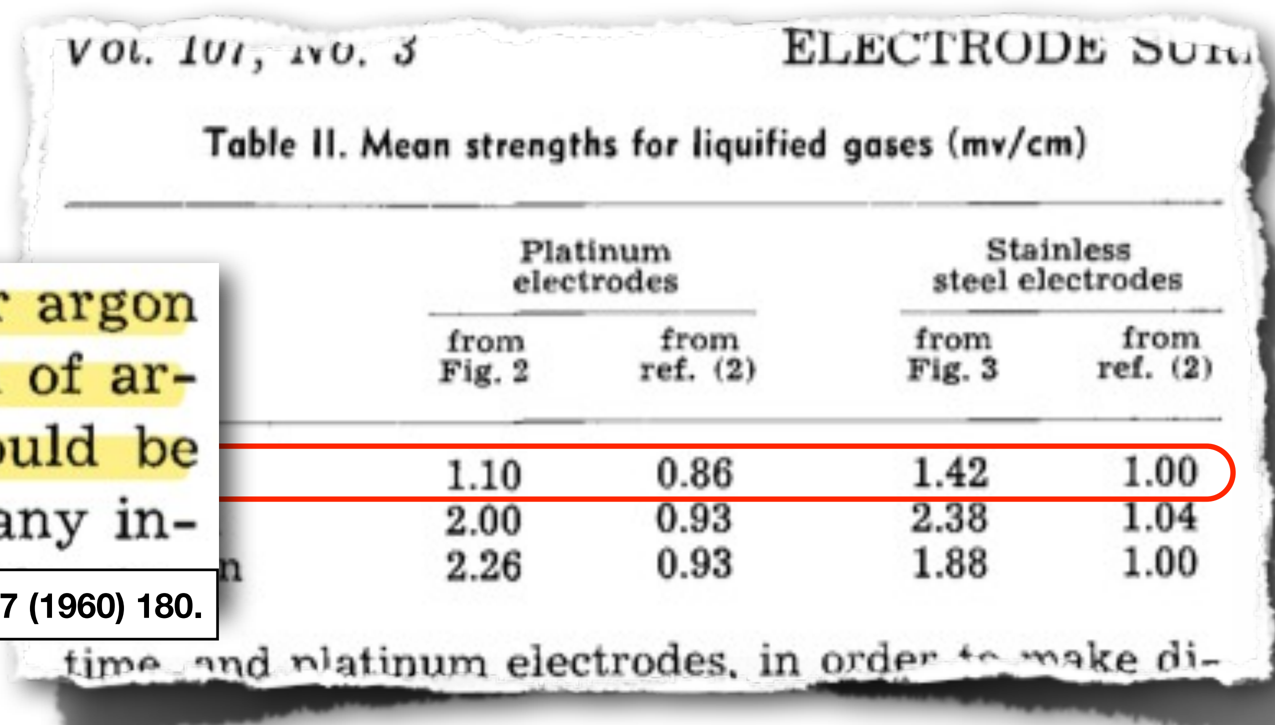
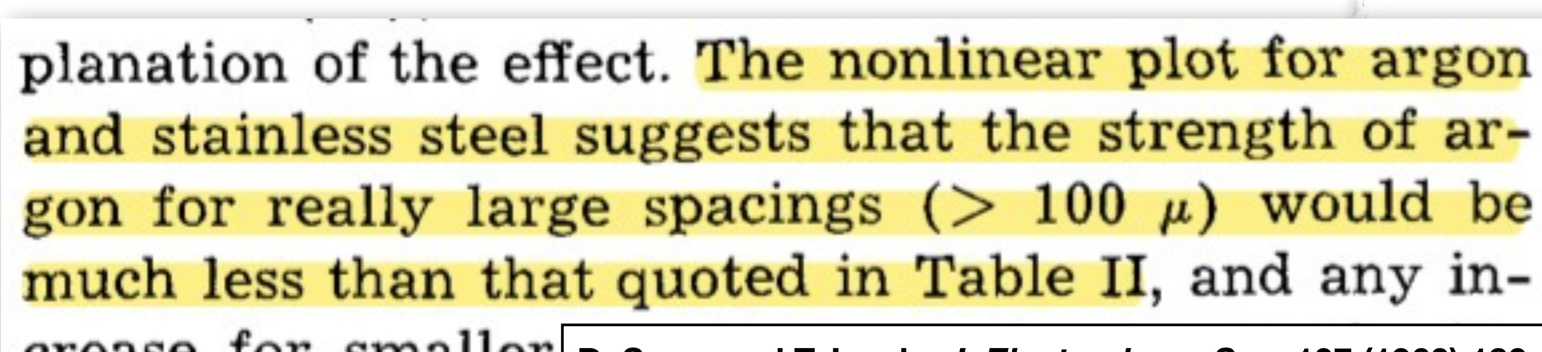


Vol. 107, No. 3 ELECTRODE SUR

Table II. Mean strengths for liquified gases (mv/cm)

	Platinum electrodes		Stainless steel electrodes	
	from Fig. 2	from ref. (2)	from Fig. 3	from ref. (2)
	1.10	0.86	1.42	1.00
	2.00	0.93	2.38	1.04
n	2.26	0.93	1.88	1.00

time and platinum electrodes, in order to make di-

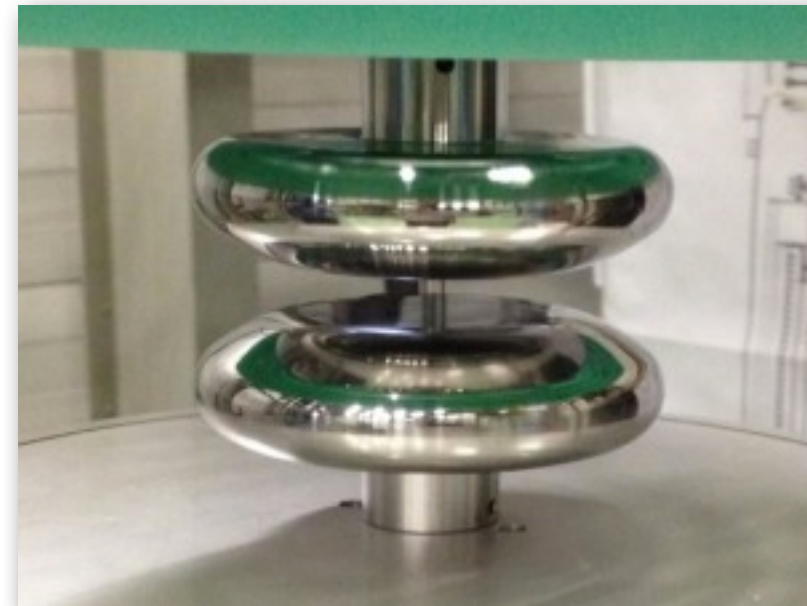


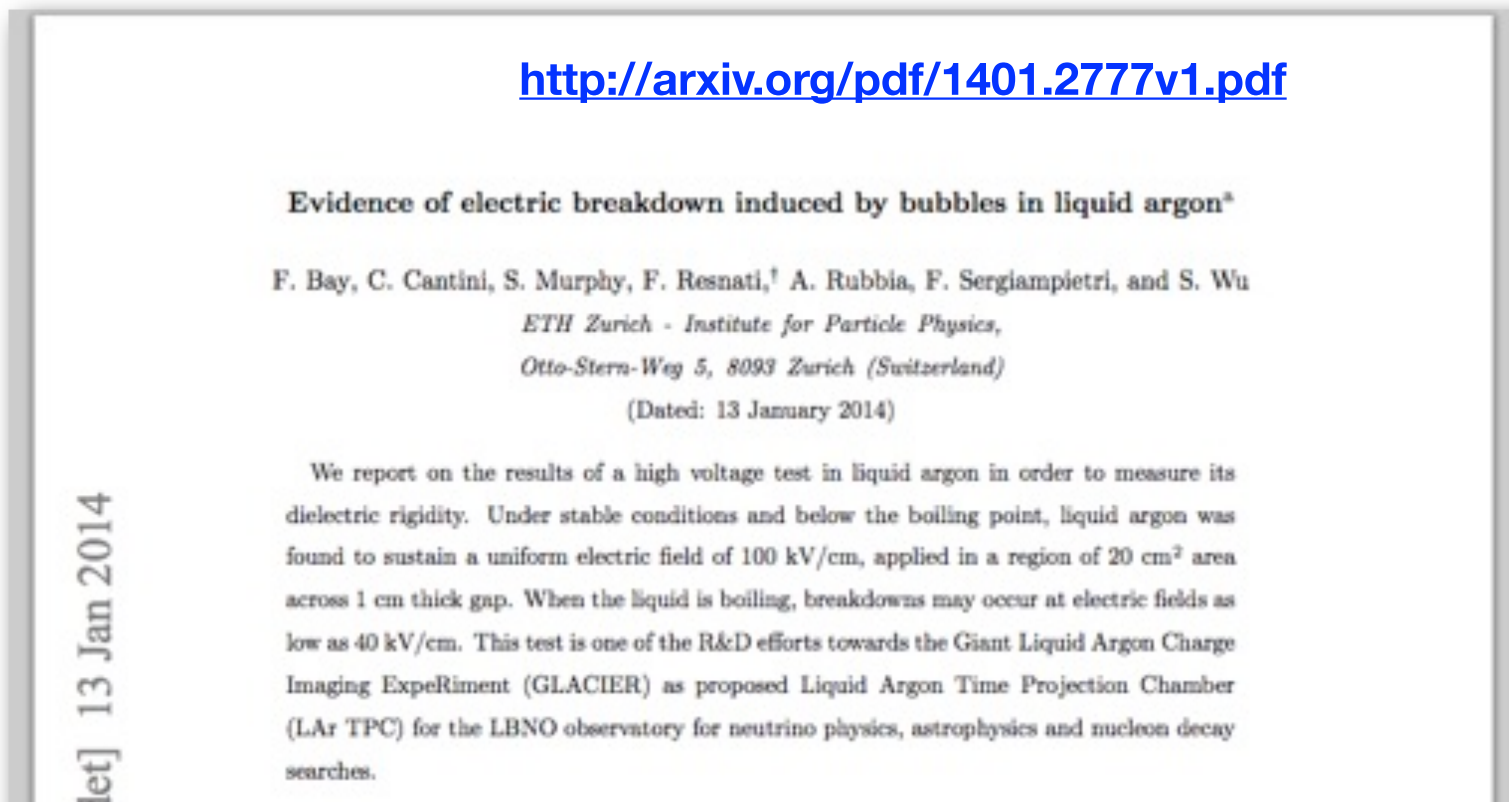
planation of the effect. The nonlinear plot for argon and stainless steel suggests that the strength of argon for really large spacings (> 100 μ) would be much less than that quoted in Table II, and any increase for smaller

D. Swan and T. Lewis, *J. Electrochem. Soc.* 107 (1960) 180.

HV Breakdown: Recent Results

- Indeed, recent results have reported much lower dielectric strength values for larger distances & geometry
  - The ETH Zurich group reported on breakdowns as low as **40 kV/cm** across a 1 cm gap between 20 cm^2 profiles in ***boiling* LAr**
    - Bubbles may induce breakdown
  - Setup also held 100 kV (PS limit) for four hours in non-boiling LAr





http://arxiv.org/pdf/1401.2777v1.pdf

Evidence of electric breakdown induced by bubbles in liquid argon*

F. Bay, C. Cantini, S. Murphy, F. Resnati,† A. Rubbia, F. Sergiampietri, and S. Wu
ETH Zurich - Institute for Particle Physics,
Otto-Stern-Weg 5, 8093 Zurich (Switzerland)
(Dated: 13 January 2014)

We report on the results of a high voltage test in liquid argon in order to measure its dielectric rigidity. Under stable conditions and below the boiling point, liquid argon was found to sustain a uniform electric field of 100 kV/cm, applied in a region of 20 cm^2 area across 1 cm thick gap. When the liquid is boiling, breakdowns may occur at electric fields as low as 40 kV/cm. This test is one of the R&D efforts towards the Giant Liquid Argon Charge Imaging ExpeRiment (GLACIER) as proposed Liquid Argon Time Projection Chamber (LAr TPC) for the LBNO observatory for neutrino physics, astrophysics and nucleon decay searches.

det] 13 Jan 2014

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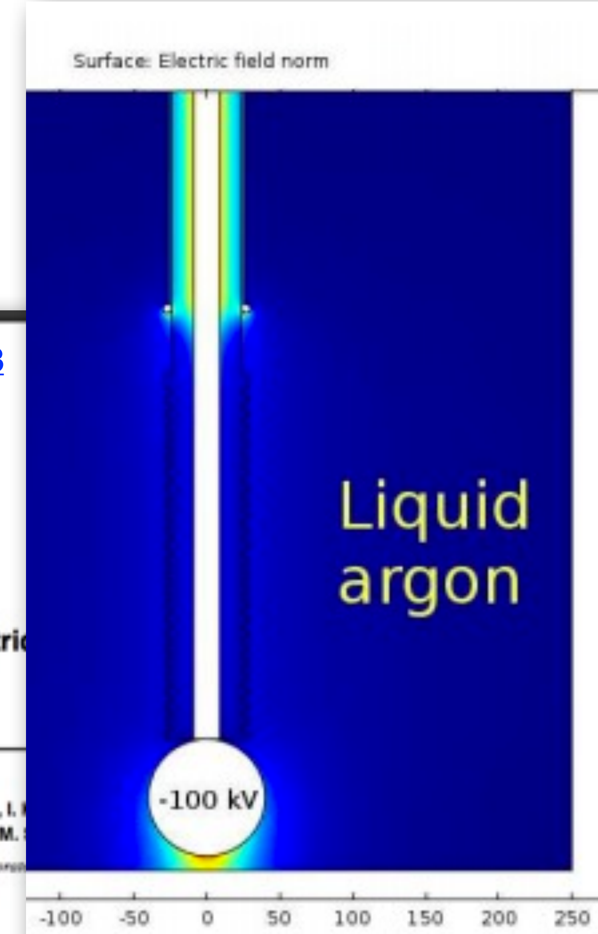
  - The Bern group reported on measurements up to the cm scale



http://arxiv.org/abs/1401.6693

arXiv:1401.6693v1 [physics.ins-det] 26 Jan 2014

Experimental study of electri…
argon at centimeter scale

A. Blatter, A. Ereditato, C.-C. Hsu, S. Janos, I. …
C. Rudolf von Rohr, M. Schenk, T. Strauss, M. …
Albert Einstein Center for fundamental Physics, Laborat…
of Bern,
Sidlerstrasse 5,3012 Bern, Switzerland
E-mail: igor.kreslo@lhep.unibe.ch

ABSTRACT: In this paper we present results on measurements of the dielectric strength of liquid argon near its boiling point and cathode-anode distances in the range of 0.1 mm to 40 mm with spherical cathode and plane anode. We show that at such distances the applied electric field at which breakdowns occur is as low as 40 kV/cm. Flash-overs across the ribbed dielectric of the high voltage feed-through are observed for a length of 300 mm starting from a voltage of 55 kV. …

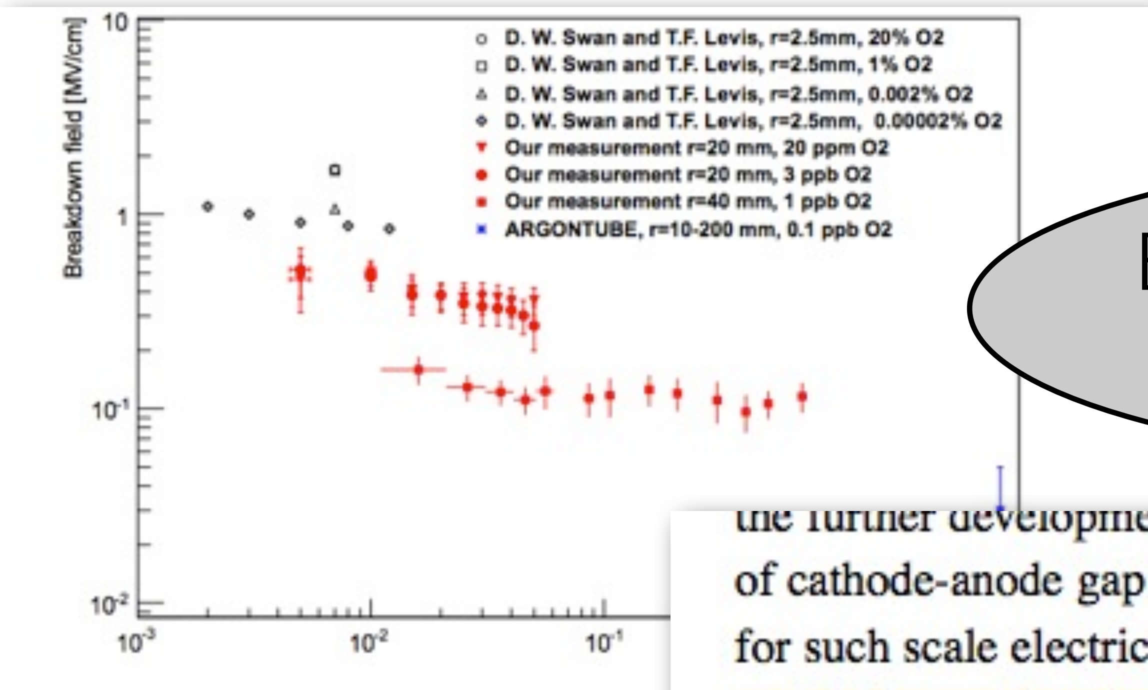


Figure 7. Compilation of the experimental data on the elect… from our measurements.

Breakdowns at fields as low as **40 kV/cm**

…the further development of the studies. The measurements presented in this paper extend the scale of cathode-anode gap widths up to 10 mm with spherical cathode and plane anode. It is shown that for such scale electric breakdowns in highly purified liquid argon (1 ppb oxygen equivalent) occur at field intensities significantly lower then expected, namely as low as 40 kV/cm. The observation of a dependence of the breakdown field on the cathode-anode distance and on the cathode shape supports the hypothesis that the breakdown is governed by space-charge effects in the volume and

HV Breakdown: Recent Results

- The Bern group has investigated increasing the max field a component can withstand under HV with a polymer coating (http://arxiv.org/abs/1406.3929v1)
  - Fields as high as 400 kV/cm were reached over several mm before breakdown
  - This could remedy some issues with cathode discharge

Xiv:1406.3929v1 [physics.ins-det] 16 Jun 2014

**A method to suppress dielectric breakd
liquid argon ionization detectors for cat
ground distances of several millimeters**

M. Auger, A. Ereditato, D. Goeldi, S. Janos, I. Kreslo, M. Luethi
C. Rudolf von Rohr, T. Strauss, T. Tolba and M. S. Weber

ABSTRACT: We present a method to reach electric field intensity as high
argon for cathode-ground distances of several millimeters. This can be a
field emission from the cathode, overcoming limitations that we reported

KEYWORDS: Dielectric strength, electric breakdown, liquid argon, Time

From http://arxiv.org/pdf/1406.3929v1.pdf

Table 1. Summary of the breakdown test measurements with 200 μm and 450 μm thick polyisoprene layers coating 5 cm and 4 cm diameter spheric cathodes, respectively.

Gap width	Max. field strength	Sphere diameter	Polyisoprene thickness	Breakdown
5 mm	298 kV/cm	4 cm	450 μm	no
4 mm	358 kV/cm	4 cm	450 μm	no
3 mm	412 kV/cm	4 cm	450 μm	yes
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3929v1 [physics.ins-det] 16 Jun 2014

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This is significantly higher than the previous breakdown measurement

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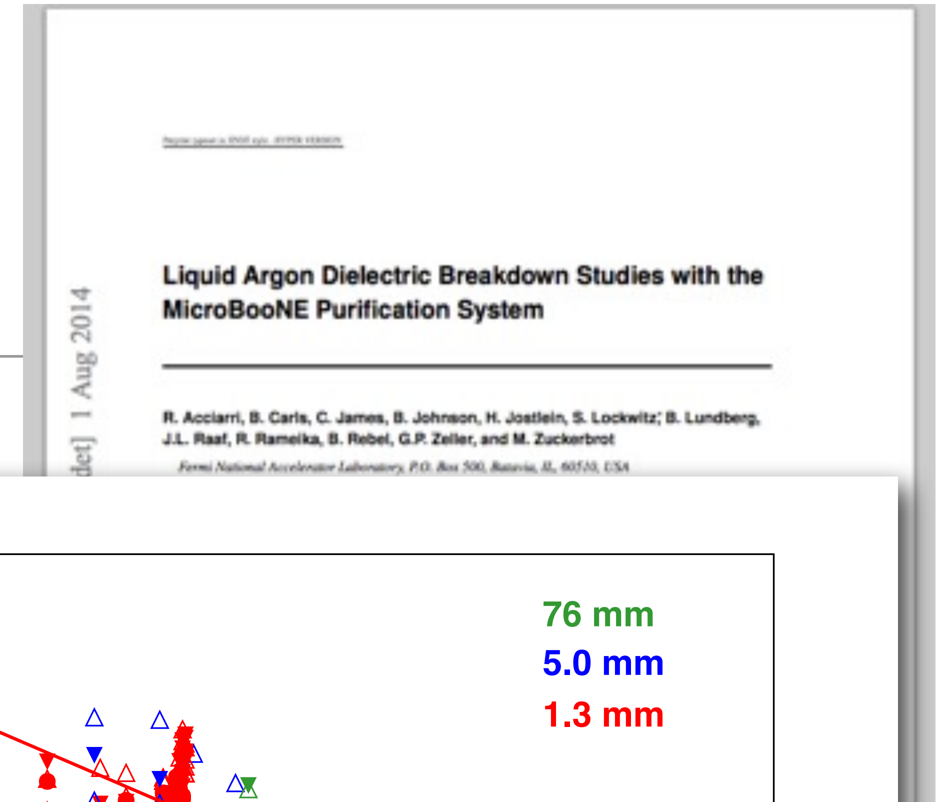
- Indeed, recent results have reported much lower dielectric strength values for larger distances & geometry
    - At FNAL, we measured breakdown vs distance and varied contamination level and cathode size (http://arxiv.org/abs/1408.0264)
    - We had breakdowns with E_{max} between ~ **40 kV/cm** to > **1 MV/cm**
    - We found a LAr purity effect with only the smallest cathode at distances ≳ cm
    - Across cathode sizes, the parameter of interest seemed to be **stressed area** (or volume)

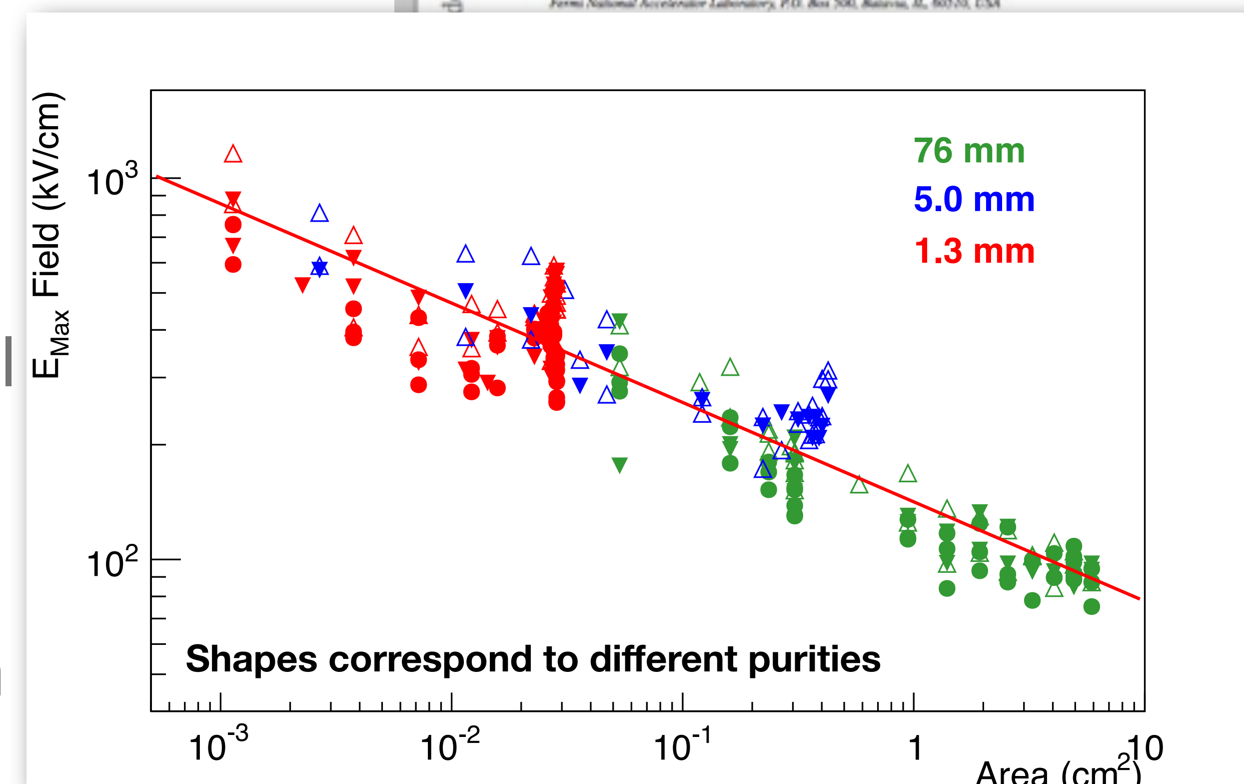


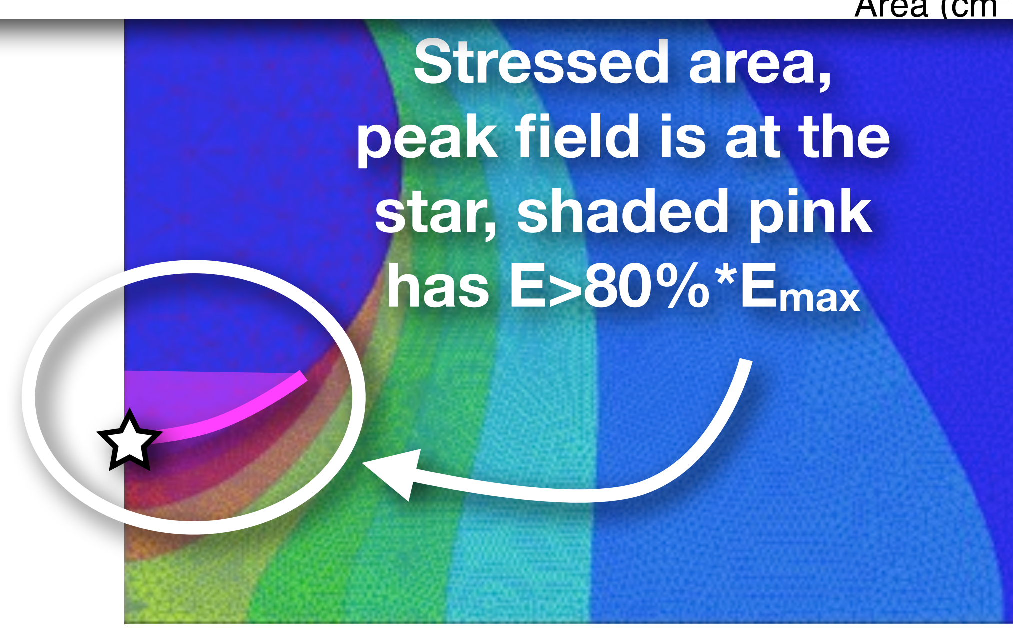
1 Aug 2014

Liquid Argon Dielectric Breakdown Studies with the MicroBooNE Purification System

R. Acciarri, B. Carls, C. James, B. Johnson, H. Jostlein, S. Lockwitz, B. Lundberg, J.L. Raaf, R. Rameika, B. Rebel, G.P. Zeller, and M. Zuckerbrot

Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL, 60510, USA





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Über Oberflächeneffekte beim elektrischen Durchbruch von Flüssigkeiten 161

mit Wechselspannungen sind vollautomatisch arbeitende Versuchseinrichtungen mit Erfolg verwendet worden[6]. Als einer der ersten hat Weibull[7] darauf hingewiesen, daß die zu erwartende statistische Verteilungsfunktion von der Gaußschen verschieden wäre und er schlug andere, unsymmetrische Typen der Verteilungsfunktion vor.

B. Die Modellvorstellung der unge

Gauster, W.F. Über Oberflächeneffekte beim elektrischen Durchbruch von Flüssigkeiten *Ingenieur Archiv* (1956) **10** 160–167

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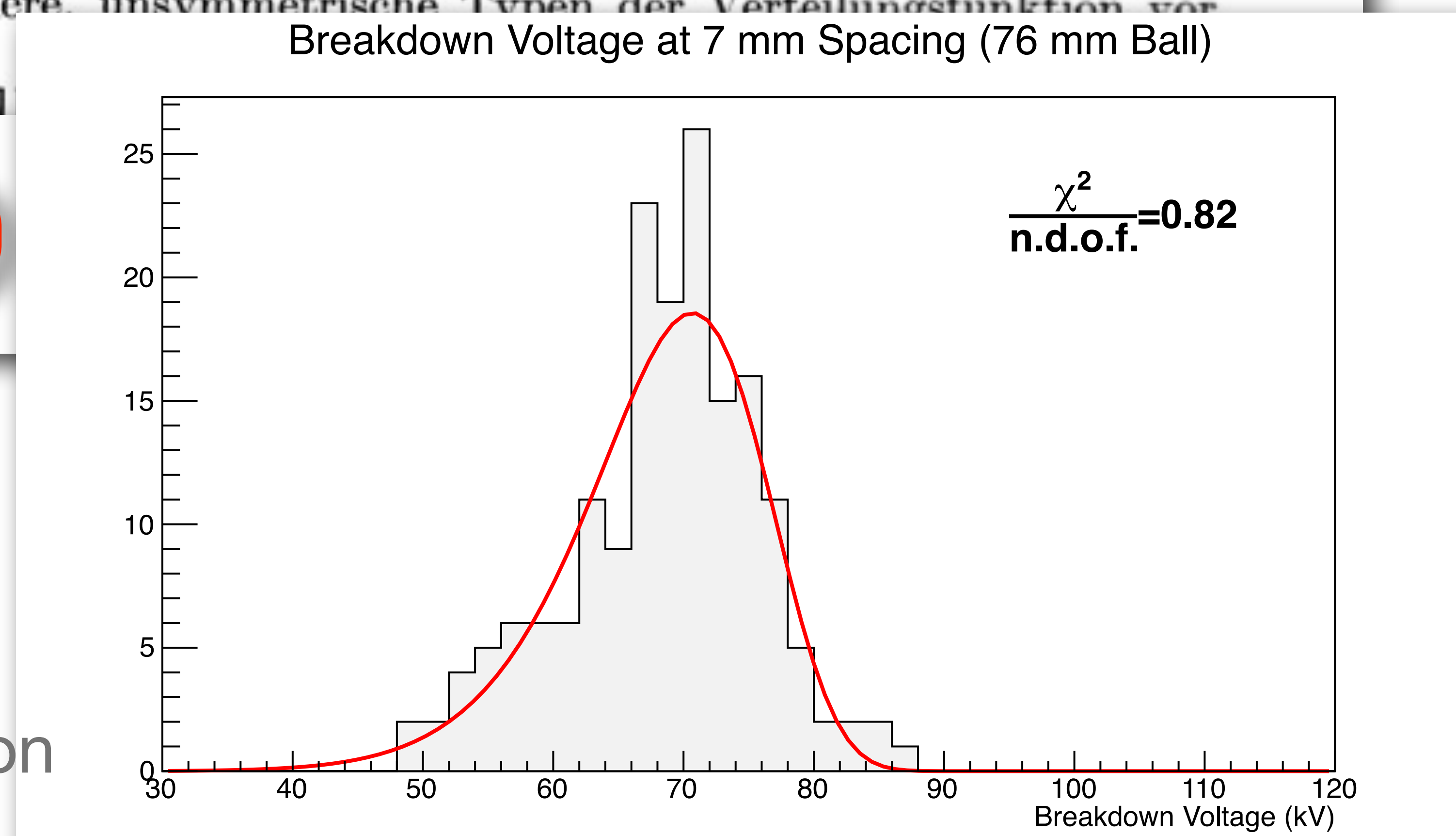

- Understanding the width and eventually how this varies in time will help define the breakdown probability for a given configuration

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    - More recombination
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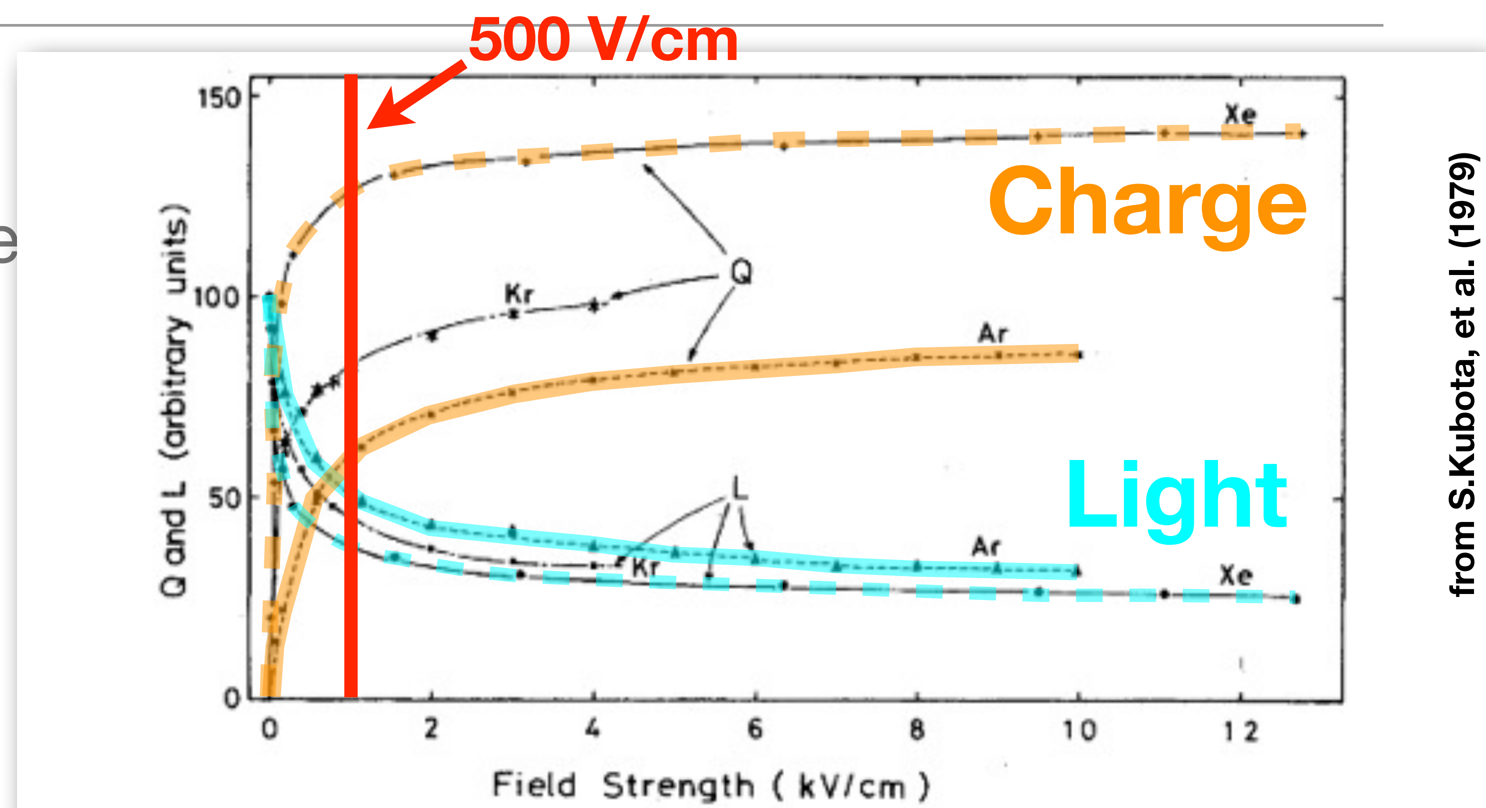

FIG. 2. Variation of relative luminescence intensity L and collected charge Q in liquid argon, krypton, and xenon vs applied-electric-field strength for 0.976- and 1.05-MeV electrons.

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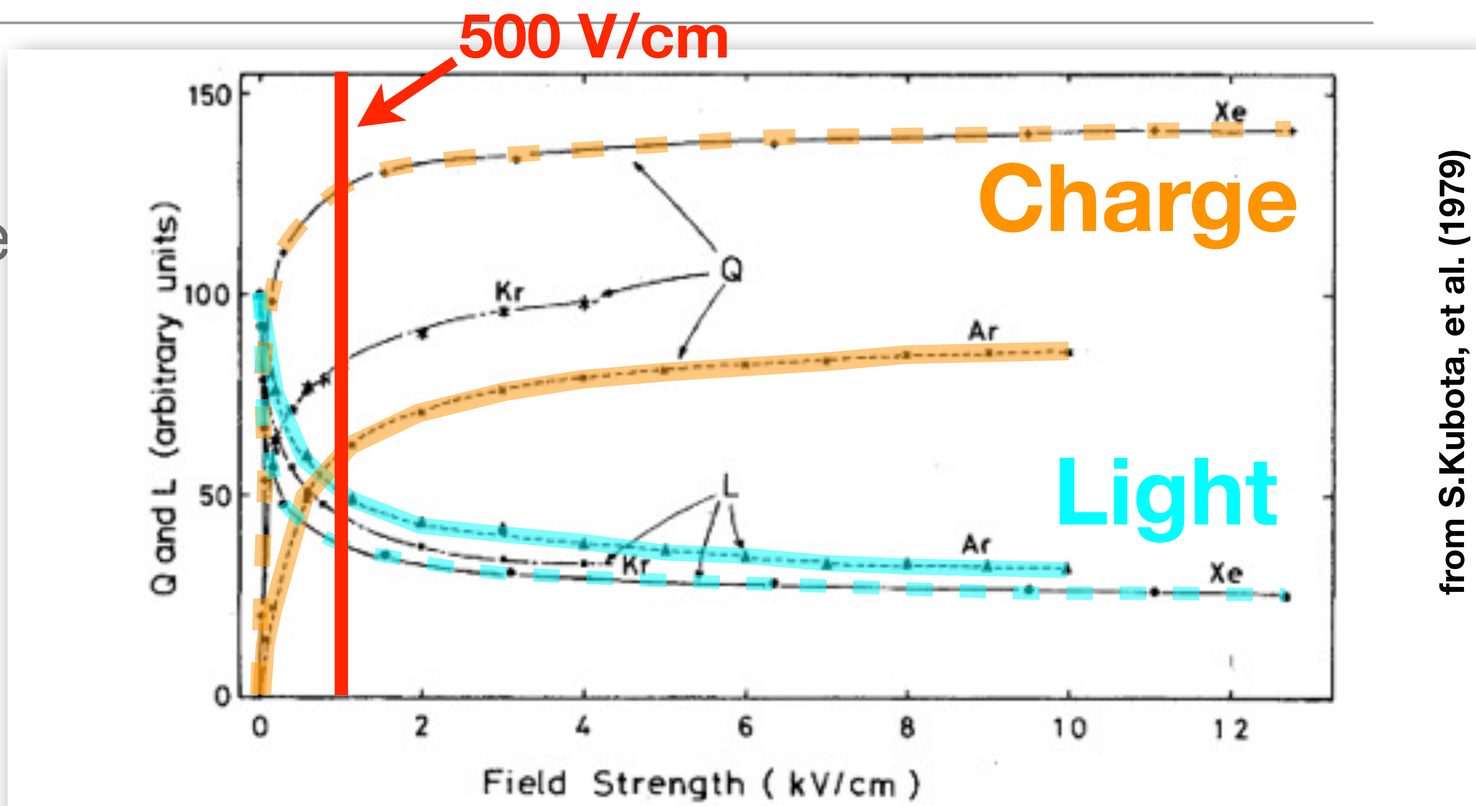

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from S.Kubota, et al. (1979)

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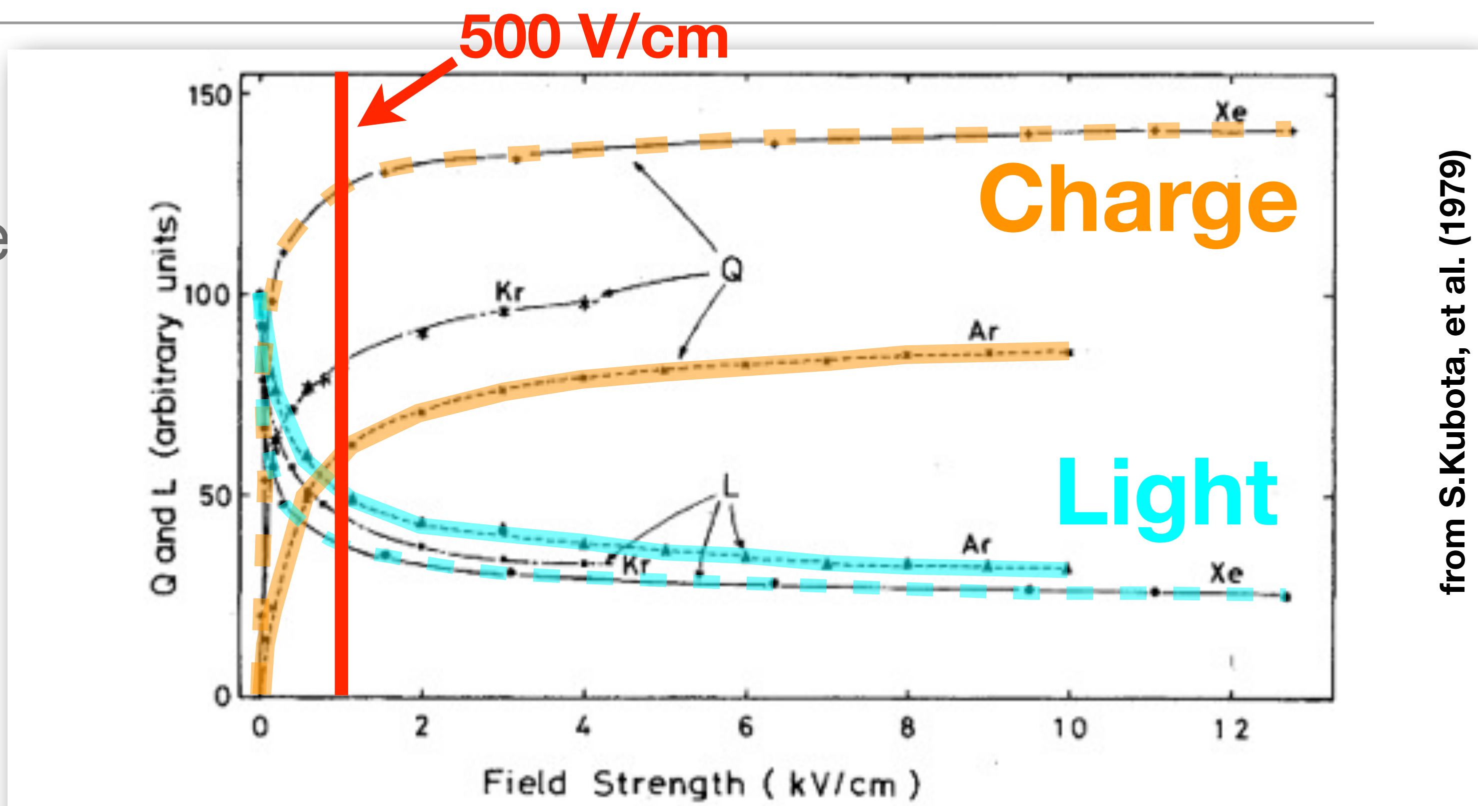
  - Greater positive ion charge build up from cosmic rays if the detector is on the surface
    - Distorts the drift field



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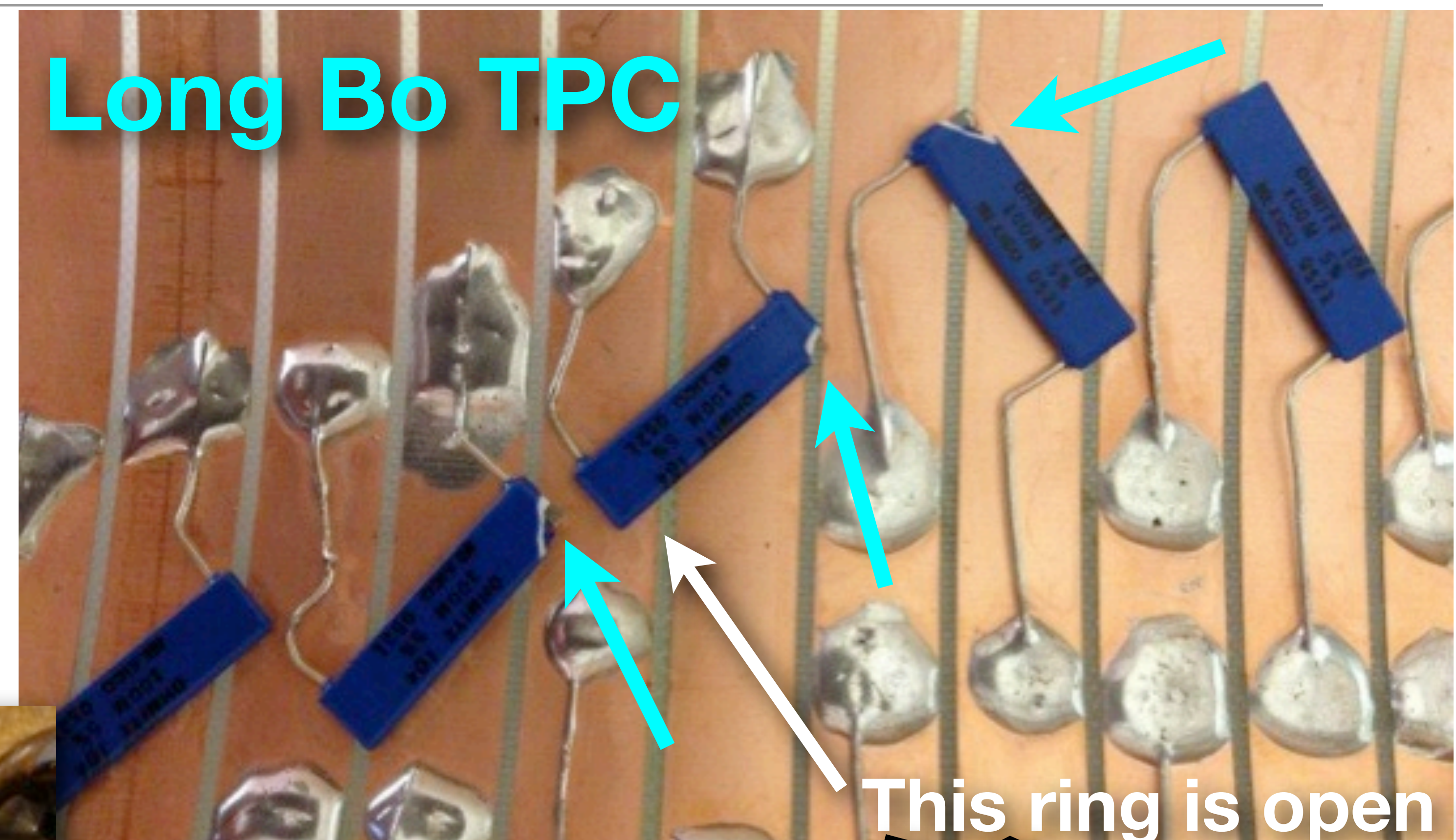
Potential Impact on Experiments

- HV breakdowns would lead to downtime and possible component damage
  - Broken resistors
  - Damaged other components with reduced, or no, functionality

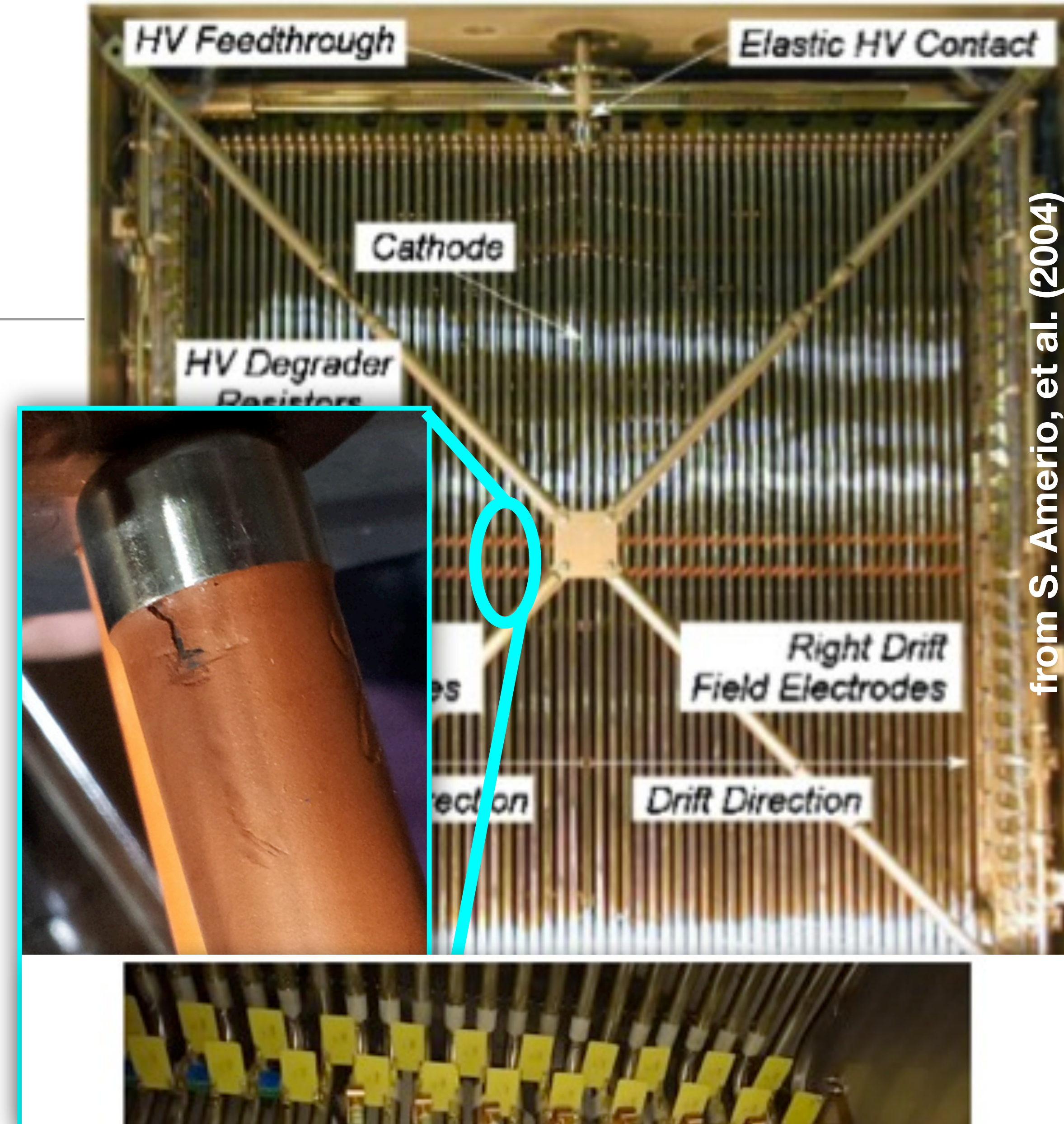


This is why you should care!

- Polyester HV test piece
- Sustained many arcs
- Eventually, severe mechanical damage

HV Damage Avoidance and Mitigation

- We often cannot access the TPCs for repairs, and downtime should be minimized
  - So we want to reduce the risk for damage
- Use robust materials
  - Durable resistors with high power and voltage ratings
    - ICARUS (rated to 24 kV in air)
    - MicroBooNE used resistors rated to 48 kV in air on the first 1/4 of the TPC (normal op. 2 kV) (http://arxiv.org/abs/1408.4013)
  - Avoid using materials that break or scar under HV stress (previous slide)



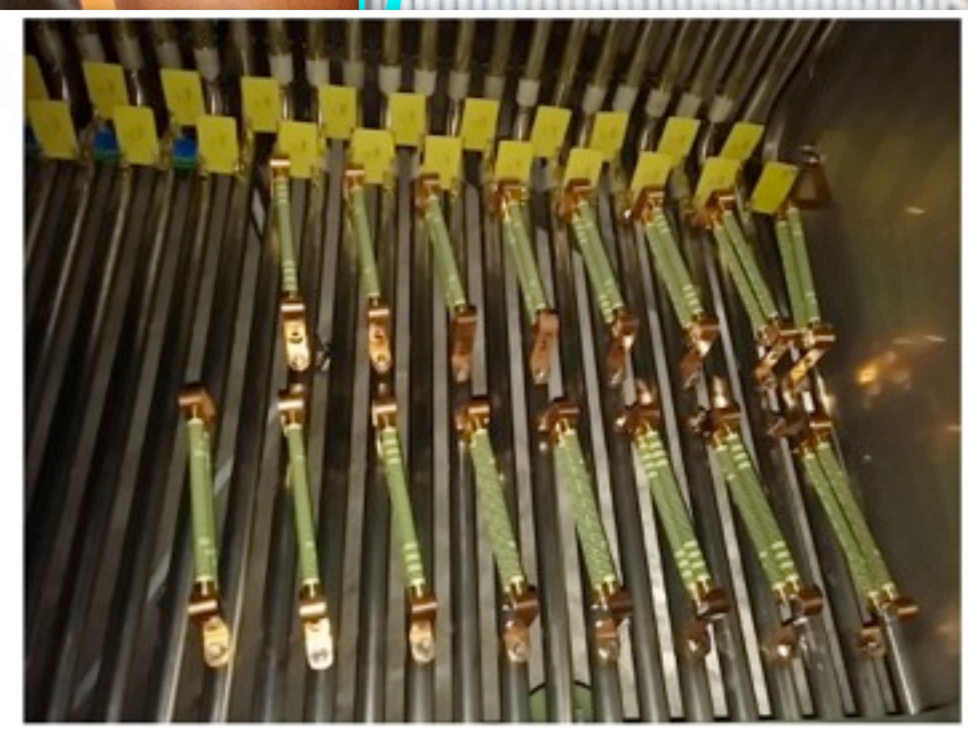
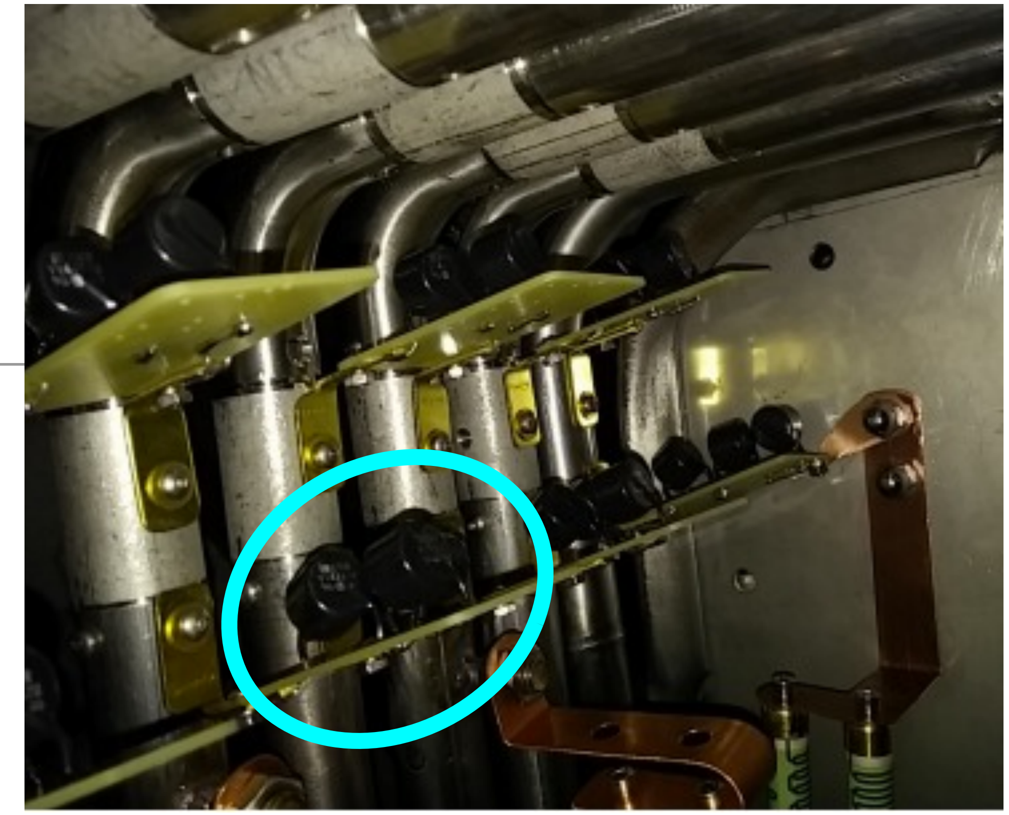
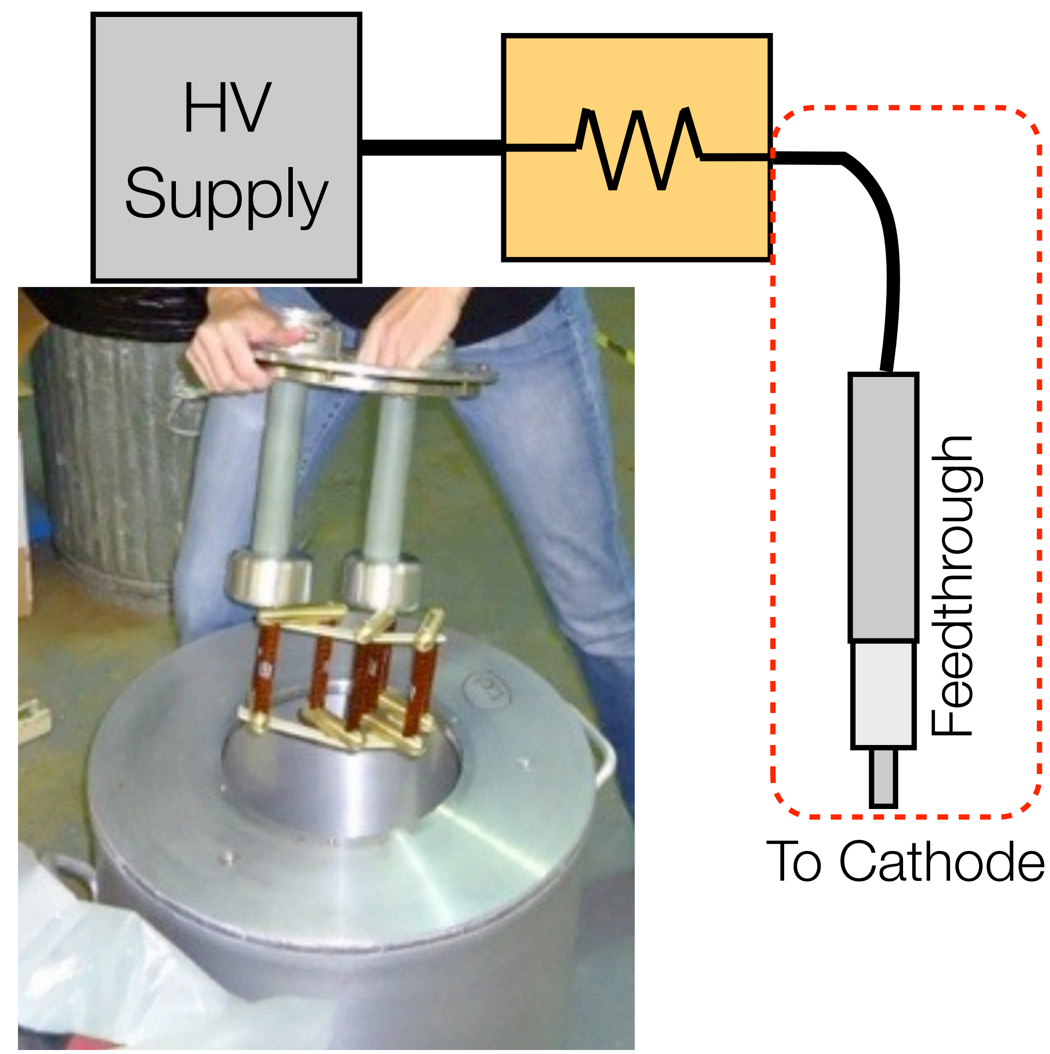


Figure 10. The Metallux HVR 969.23 resistors mounted on the 16 field cage loops closest to the cathode.

HV Damage Avoidance and Mitigation

- Surge Protection
  - If the feedthrough or cathode discharges, very high voltages can appear across the field cage resistors
  - MicroBooNE installed varistors on the higher voltage 1/2 of the TPC to protect the resistors
  - Gas discharge tubes (GDTs) were also investigated and found to be suitable (http://arxiv.org/abs/1406.5216). Used in LArIAT.
- Isolate the stored energy
  - A resistor upstream of the feedthrough (or cathode) avoids releasing all of the stored energy in the cable into the cryostat in the event of a discharge





Closing Remarks

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- While LArTPCs have run successfully in the past,
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    - Some metrics on insulator performance
      - For feedthroughs
      - And because TPCs are constructed with insulators

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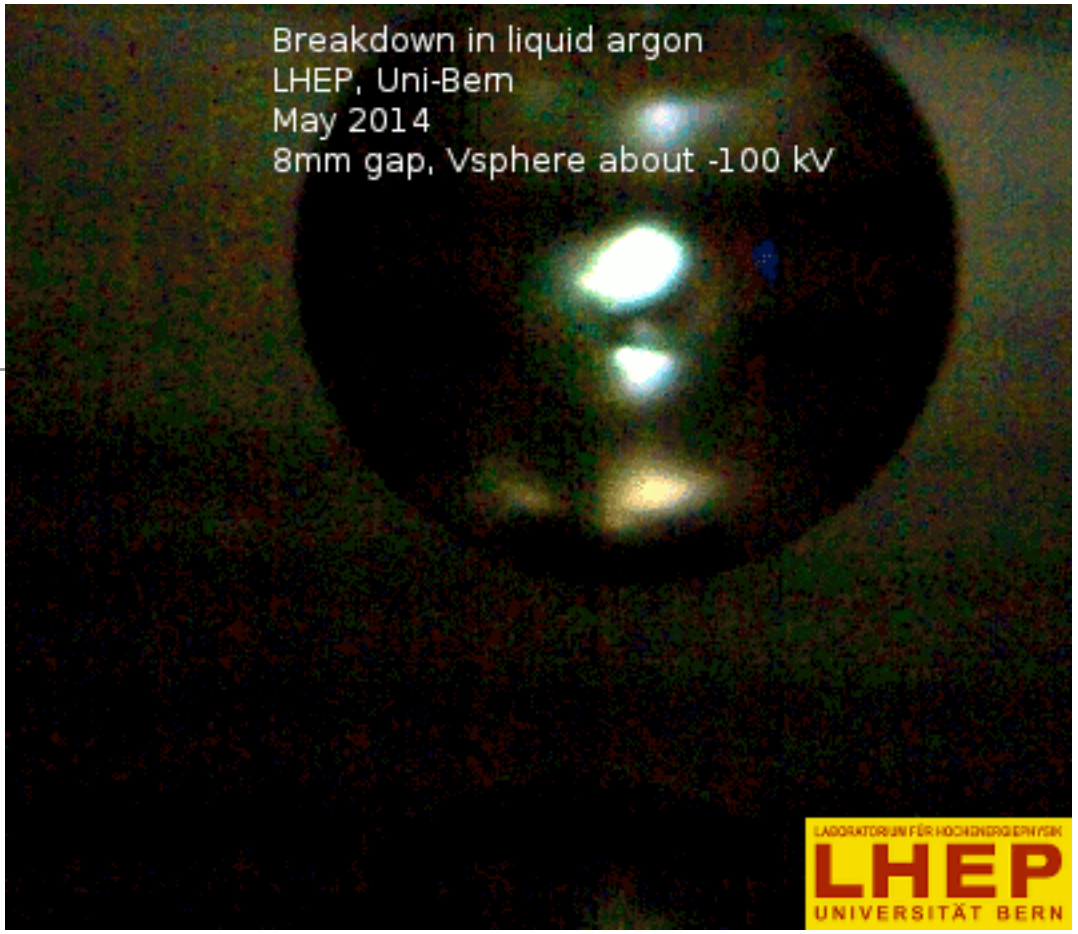

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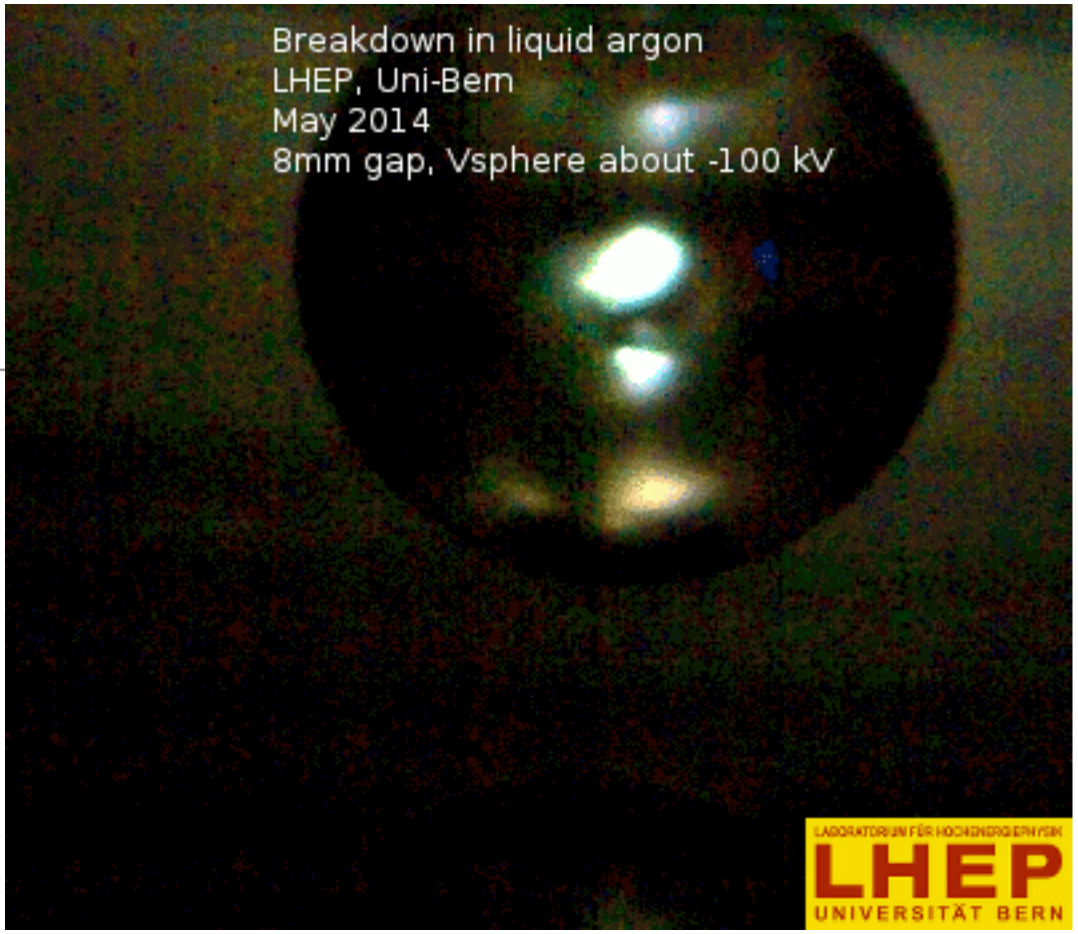

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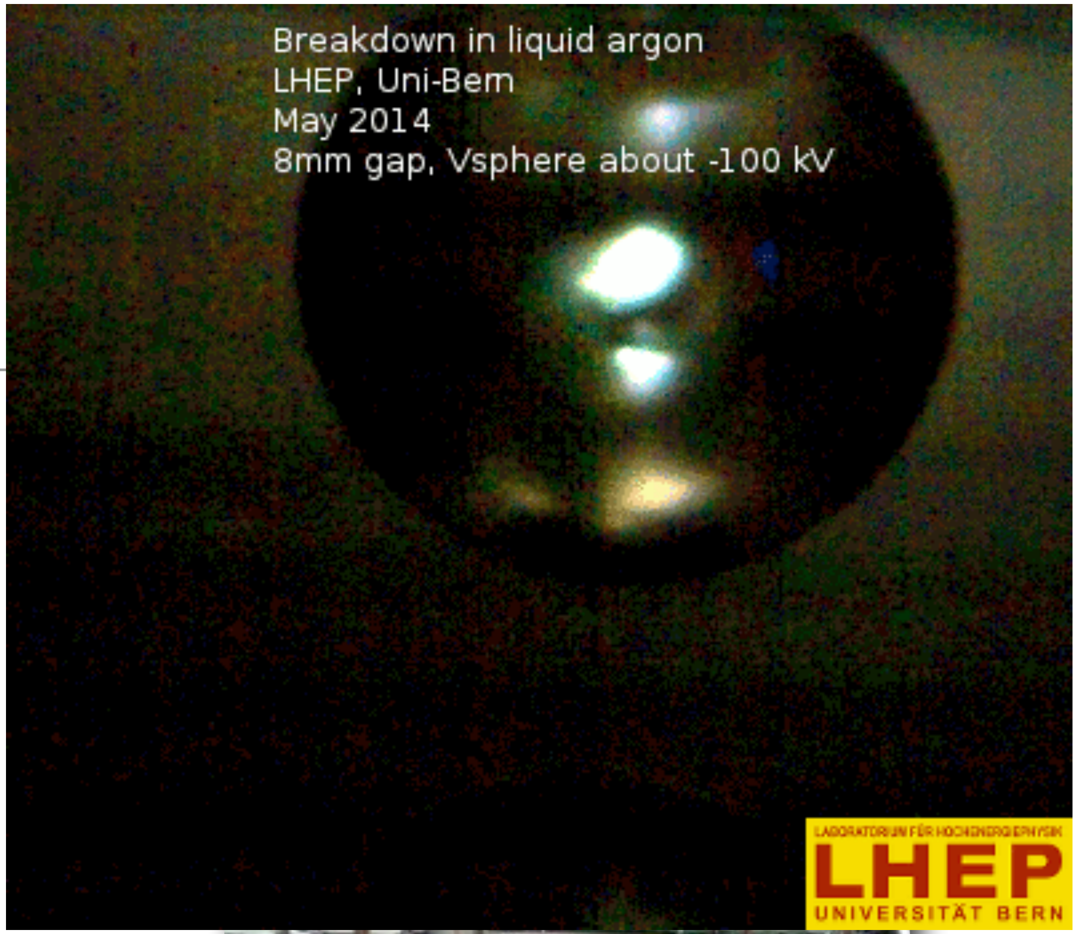

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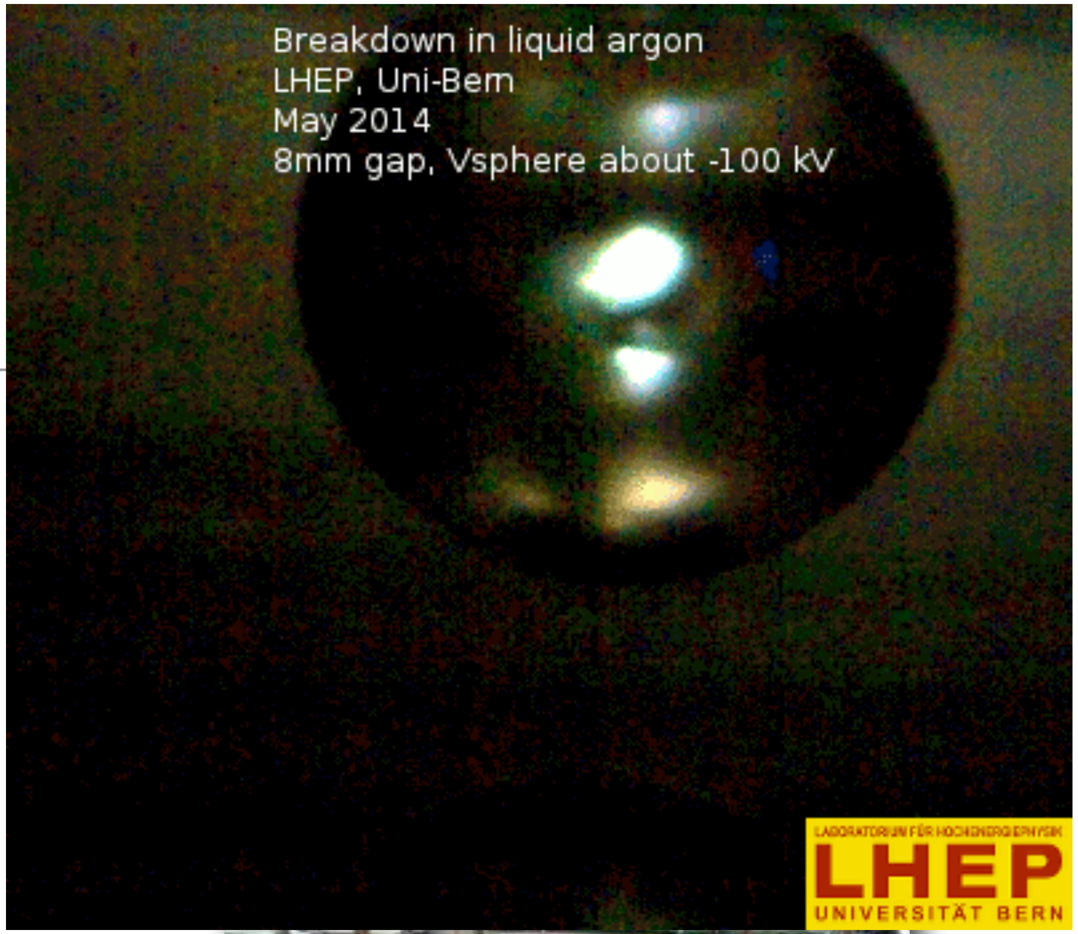
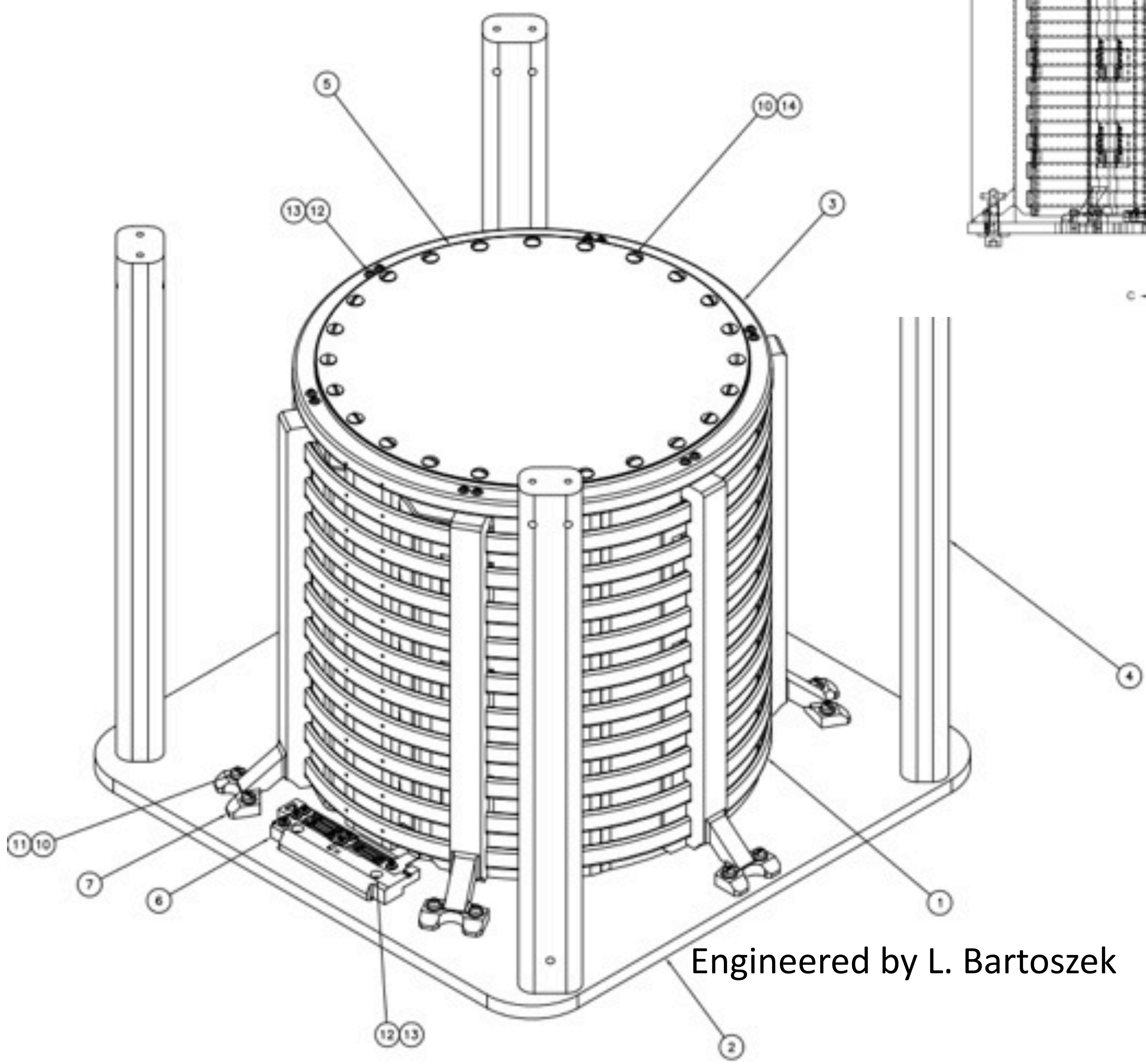
  - Thank you for your attention!



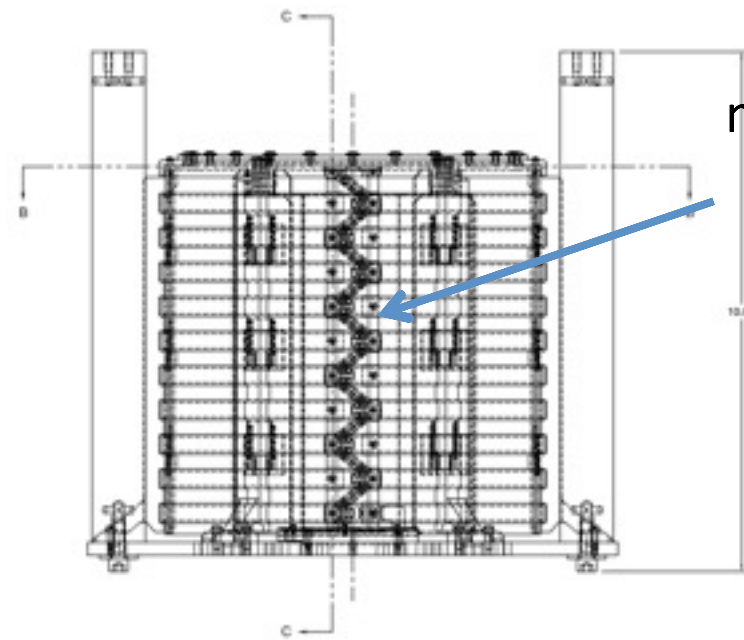
Back Up Slides

Phase II : Bern LXe cell miniEXO TPC mockup tests

The miniEXO TPC :
½ EXO-200 dia., one "anode"

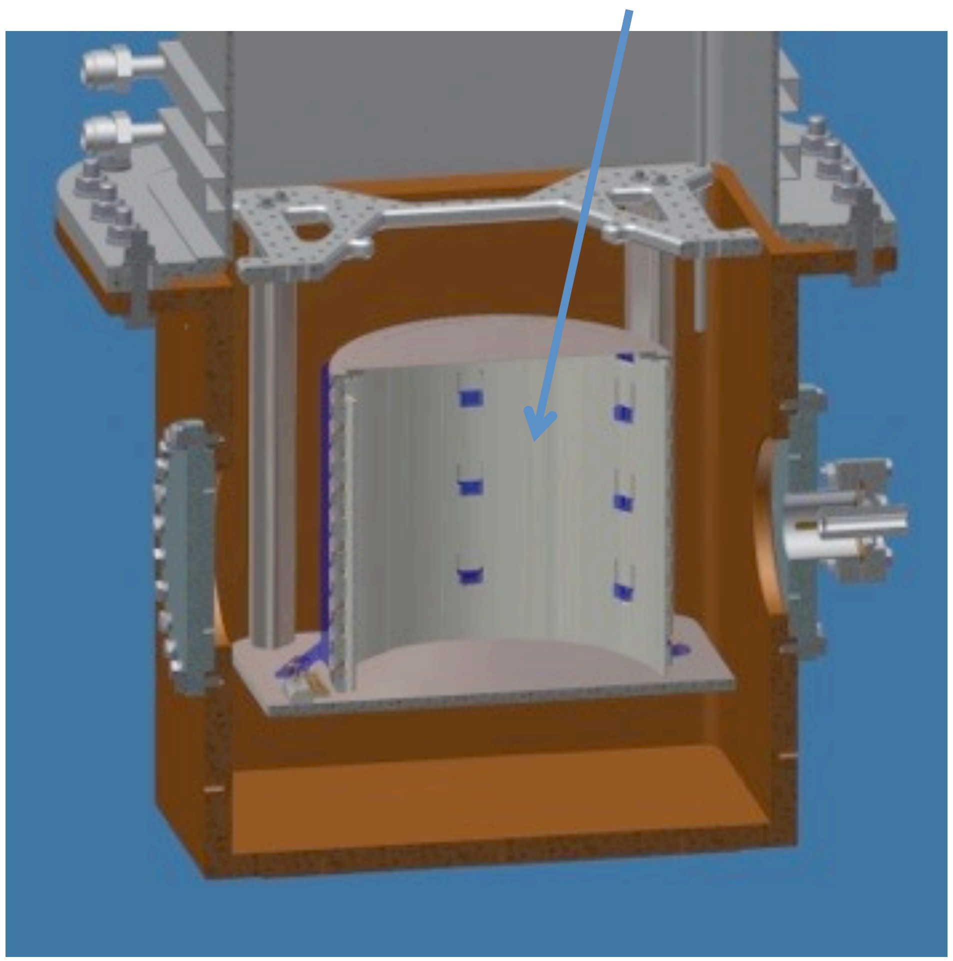


Engineered by L. Bartoszek



Detail showing voltage divider mounted on acrylic outside of teflon reflectors as in EXO-200

Bern cryostat with miniEXO mockup installed (cross section with reflectors visible.)



HV testing of the miniTPC mockup : plans at Bern

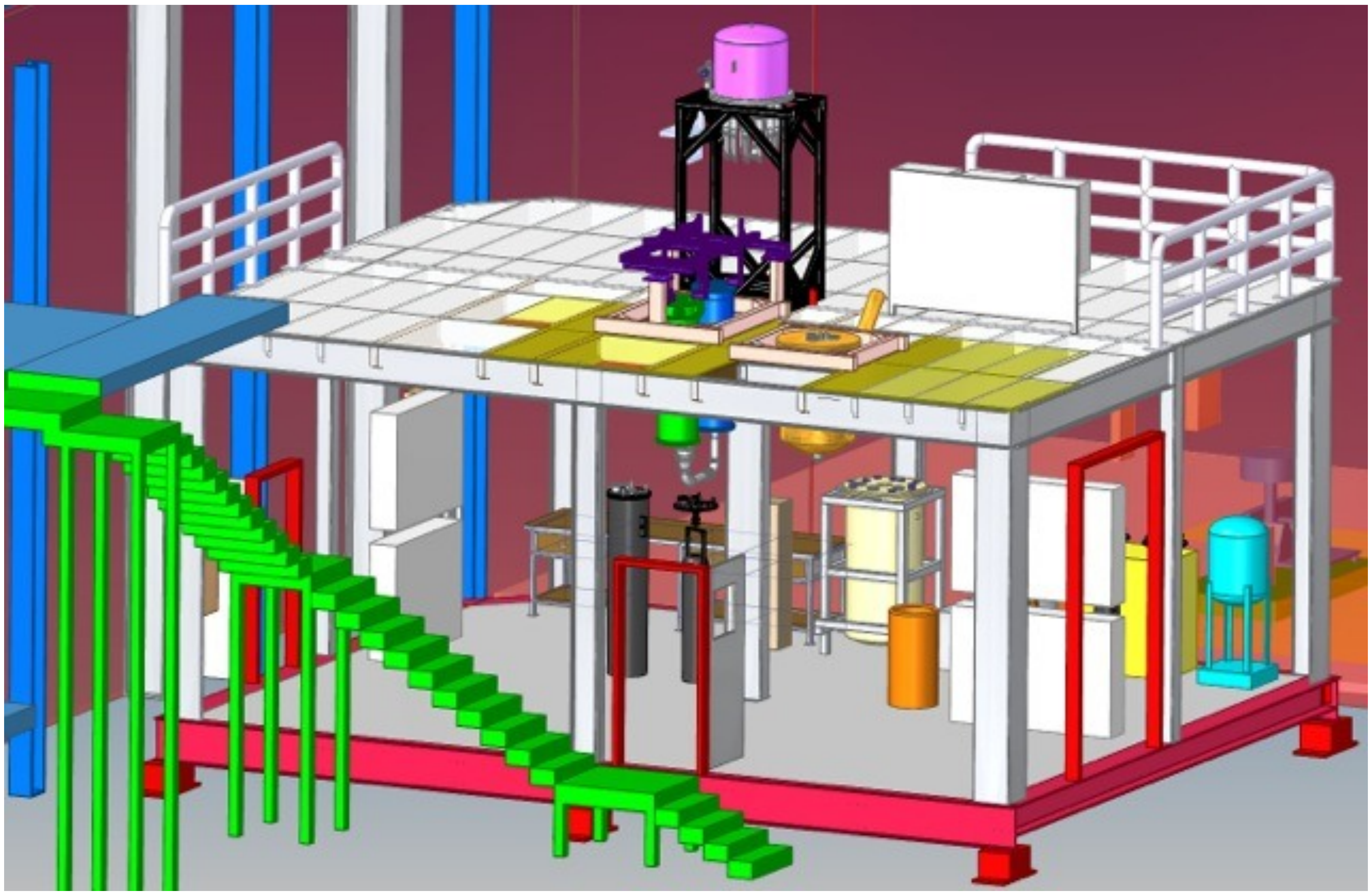
1. Complete testing/characterization of the Bern LXe cryostat including purity measurement (with the Bern TPC installed).
2. Warmup, complete miniTPC assembly (cathode), install in cryostat.
3. Low voltage test
4. Clean up : pump down followed by room temp xenon gas recirculation.
5. HV test
   1. Raise voltage (max of 40 kV).
   2. Camera(s) images any discharges
   3. "Glitch detector/scope" used
6. Decision point depending on what is seen. Possible choices :
   1. Remain cold – attempt to change purity
   2. Warm up – HV retest in gas
   3. Warm up – Open cryostat, modify miniTPC, retest

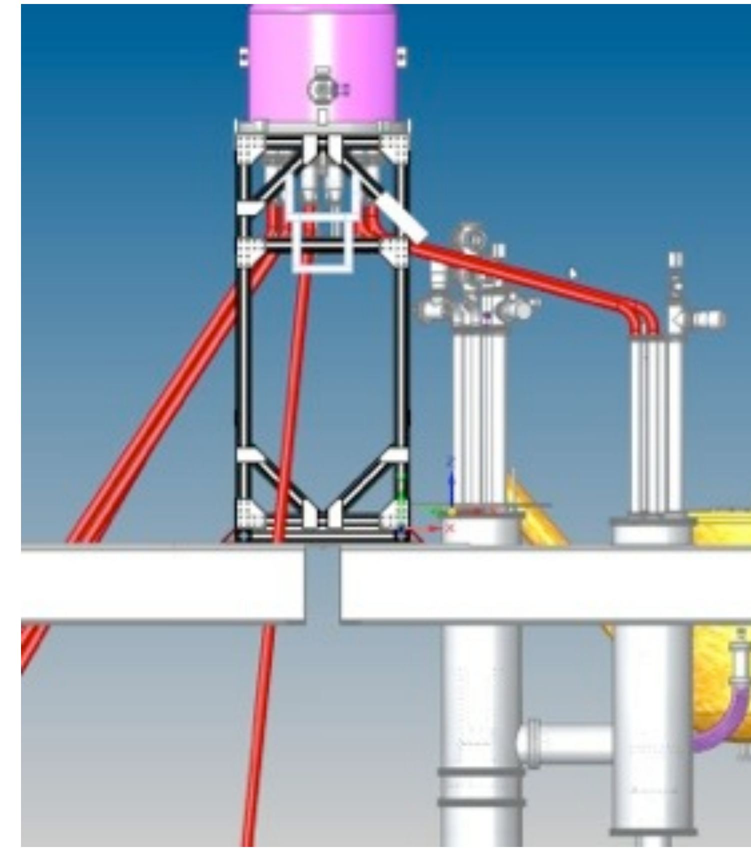
I plan to travel to Bern in February to work with Razvan with possible assistance from Sebastien.

Phase III – Planning just recently begun

- **Mike Heffner and Allen House and I have discussed ideas – both Mike and Allen have been to SLAC to see the setup in our lab.**
- **In broad summary, the test cells would include a small diameter full-drift-length version for testing the nEXO voltages for full field, and a larger radius cell to accommodate full or near-full size parts horizontally.**
- **In addition, a study of testing in gas (full scale parts) is a good idea.**
- **I have spoken to LZ leadership re: their HV setup. It turns out this setup is designed to accommodate additional setups like ours. This is an attractive option. Logistics, timing, details need to be discussed .**

The LZ test setup at SLAC in a former PEP IR is due to begin operation late this coming spring. Cooling is provided by thermal siphons, and several extra ports are provided. There is a xenon recirculation and purification system (max flow they wish to study is high – 500 SLPM). There is much extra "floor space".





Above the LN dewar is shown, with the associated thermal siphon umbilicals.